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October 1st, 2020

Ms. Karlene Fine
Executive Director
North Dakota Industrial Commission
State Capitol – Fourteenth Floor
600 East Boulevard Avenue
Bismarck, ND 58505

Re: Proposal entitled "ELECTROSTATIC FILTRATION OF LARGE LUBRICANT RESERVOIRS"

Dear Ms. Fine:

The University of North Dakota Institute for Energy Studies is submitting a proposal in response to the Lignite Research Program request for funding. In the proposed project, UND and Electrostatic Lubrication Filtration (ELF) will continue its successful development of the Electrostatic Filtration Lubrication (ELF) technology. In prior work, the project team established proof of concept for the technology to filter turbine oil to ISO standards, reducing downtime of coal-fired power plants and reducing acquisition and disposal of oil. Coyote Station and Leland Olds have committed their support for the technology by offering their facilities to conduct extended testing. The attached proposal requests $151,494 from the North Dakota Industrial Commission for the 12-month project. The total value of the project is $350,948.

The $100 application fee has been submitted electronically using ACH. A hard copy of the proposal will be sent using regular mail.

Do not hesitate to contact me with questions or requests for additional information.

Sincerely,

Michael D. Mann

Michael D. Mann, Ph.D.
Director, Institute for Energy Studies

c.enc
Mike Holmes, Lignite Energy Council

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ELECTROSTATIC FILTRATION OF LARGE LUBRICANT RESERVOIRS

Submitted to:

Ms. Karlene Fine
North Dakota Industrial Commission Lignite Research Program
State Capitol
600 East Boulevard Avenue, Department 405
Bismarck, ND 58505-0840

Funding Requested: $151,494

Submitted by:

Institute for Energy Studies
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October 1, 2020

ELECTROSTATIC FILTRATION OF LARGE LUBRICANT RESERVOIRS

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ELECTROSTATIC FILTRATION OF LARGE LUBRICANT RESERVOIRS

1. ABSTRACT

To ensure the reliable operation of lignite coal-fired power plants in North Dakota, the turbines and hydraulic systems require thousands of gallons of lubricant, which must be monitored and maintained. These lubricants must be periodically cleaned or replaced to maintain the mechanical system's integrity or be at risk of failure due to the buildup of soluble varnish, water, or contamination by sub-micron foreign particles. Maintenance, either regular or unexpected, can create extended downtime for a system, costing a plant with a 10,000-gallon lubricant reservoir up to $300,000 per day. ELF Technology, LLC. (ELF) has a patent pending for a novel product to maintain the lubricant cleanliness within ISO 9000 standards. This product extends the usable life of the lubricants, prolongs the equipment's lifespan, and avoids costly shut-downs of the plant, all of which will increase the value of North Dakota sourced lignite coal. Two ELF prototype units were built and tested with funding from a prior North Dakota Department of Commerce project. Beta tests were performed using a slipstream of oil from two North Dakota power plant turbines to provide proof of concept for the process. An estimated commercial price of a single ELF unit is approximately $82,500, only 25% of the cost for a one day-long plant shut down.

The objectives of this proposed project will add to previous development work by:

1) Conducting a more robust field demonstration at two North Dakota power plants, with real-time in-line fluid analysis.
2) Designing and fabricating two additional units to meet each plant's full-load capacity and demand by developing the specific operating and construction requirements for full-scale applications.
3) Developing ISO standards to increase reliability and establish confidence in the technology for the increased chance of industry adoption.

The proposed project will involve developing a compact and cost-effective electrostatic oil cleaner system that will allow power plant equipment to operate with a lower risk of failure due to contamination. This cleaning system will lower maintenance costs, extend lubricant lifetime, reduce wasted oil, and decrease downtime.

ELECTROSTATIC FILTRATION OF LARGE LUBRICANT RESERVOIRS

2. PROJECT SUMMARY

There are several benefits related to the adoption of the new ELF technology:

- Demonstrating the newly developed internal particle sensing device to provide real-time data on the state of the oil while eliminating the traditional maintenance operations of sampling and lab testing lubricant oil reservoirs, saving both time and expense.
- Obtaining real-time data on oil condition gives maintenance staff the information needed for faster decision making, enabling the ability to detect sudden increases in specific contaminants that indicate component wear before catastrophic failure.
- Deploying this new technology increases the life of the lubricant fluids, lowering the cost of oil replacement.
- Utilizing the particle sensor's control logic, the operational staff will be notified when the contamination level exceeds preset parameters.

The ELF initiative, proposed to the Lignite Research Program, will demonstrate the technology's efficacy and the value the power generating plants will realize. The system's ability to filter the lubricant to a sub-micron level and the particle sensing capabilities of ELF will be validated by providing real-time, continuous data on the lubricant's condition. The power generation facility will monitor the reservoir condition remotely without the need for a lengthy testing regimen of sampling the oil and sending it to the laboratory. The project aims to have developed and demonstrated the technology at a commercially relevant scale and begin commercial deployment following successful project completion.

3. PROJECT DESCRIPTION

ELF anticipates running two trials at the Coyote Power and Leland Olds Generation Facilities. These trials will run for approximately 90 days each, providing real-time analysis of the reservoir and cleaned lubricant, and will produce a series of daily oil samples for testing at a certified lab. The data's accuracy from the continuous particle sensing device will be validated against the ISO Certified lab data. The combined data from both the sensor and the daily oil samples will be used to validate that the technology cleans the oil to levels better than those recommended by the turbine manufacturer and that the built-in particle sensing technology accurately reflects the condition of the oil as verified by the results from a third-party lab.

ELF will permanently place their units in conjunction with turbines at the above-referenced power plants once the preliminary stage is complete.

3.1 Overall Project Goal

This proposed work aims to develop and demonstrate the ELF Technology's ability to clean and maintain lubricating oil at or below an ISO 4406 Fluid Cleanliness Code value of 17/16/13, a conservative standard required by North Dakota power generation stations. Another goal is to fully develop and demonstrate real-time, continuous analysis of the fluid's cleanliness. Upon successful demonstration, ELF units will transition from being research units to being available for the application and adoption by coal-fired power plants across North Dakota.

3.2 Project Objectives

In conjunction with the University of North Dakota (UND) College of Engineering and Mines, the ELF team will fabricate two units, both containing the Fluid Life Particle Sensing Technology, for field validation and technology scale-up analysis. This phase for ELF system development aims to conduct field trials, validating the Sensing Technology's ability to monitor the lubricant reservoir as the system generates real-time and continuous analysis. This data stream will be available to the maintenance staff of the power generation facility as well as ELF and UND. Independent sampling will take place daily, and identical samples will be analyzed at both the UND Material Characterization Lab and a third-party ISO certified independent lab to ensure the particle sensing device provides accurate and reliable data.

In addition, the ELF and UND teams will maintain a detailed documentation process to ensure the integrity of the newly developed ELF system, including the verification of the Fluid Life Particle Sensing Technology in its ability to return the used oil to an ISO 9000 Compliant status. ELF will then begin the process of obtaining ISO 9000 Certification, which will create an additional level of confidence in meeting the high standards of the Power Generation community.

We estimate project completion after 12 months from the release date of the funding. The benefits realized directly by the North Dakota power generation community include:

1) Eliminating the requirement of removing and replacing the turbine oil to achieve the manufacturer's recommended ISO compliance.
2) Ensuring the turbine is continuously operating with ISO compliant or cleaner oil.
3) Providing early indications of a surge in contaminant levels and detecting the imminent failure of critical components.
4) Decreasing unnecessary downtime and the associated cost of reduced power generation from the scheduled maintenance of an off-line turbine.
5) Saving plant personnel time by reducing the required sampling and lab testing
6) Reducing costs associated with the acquisition and disposal of waste oil

This project will allow the testing of the ELF Technology at a full-load capacity for the named power generation systems by fabricating two additional ELF units. These ELF units will be designed and manufactured by UND with input from the ELF team. The two proposed field demonstrations are full-scale tests in turbine generators at two of North Dakota's power plants. The Leland Olds Station and Coyote Station, both in Mercer County, have been asked to participate in this endeavor (see attached letters of commitment). Data analysis will be completed with samples collected by a certified lab independent of the ELF team.

3.3 Scope of Work

Two ELF prototype units without the particle sensing technology have been built at UND through a prior project funded by ELF and the North Dakota Department of Commerce (NDDOC). In November 2019 and February 2020, beta tests of the apparatuses were performed at the Coyote and Leland Olds Power

Generation Facilities with some of the NDDOC funds. These tests produced promising results and increased confidence in the technology. The proposed work increases the test duration from 30 to 90 days, augmenting the range of the dataset and showcasing the attributes and value propositions of the ELF technology. The longer-term testing and subsequent post-test analysis of the filter elements will be used to project the lifetime of the filter. This extended equipment lifetime is critical for major commercial deployment and identifies the turnover or downtime required to maintain the ELF unit.

TASKS TO BE PERFORMED

Task 1.0 – Project Management and Planning: This task includes all work elements required to maintain, revise, manage, and report on activities within the Project Management Plan. This plan also includes the activities to ensure coordination of the project with ELF/LEC and other project participants. UND will be responsible for the completion of this task

The ELF management team will collaborate with the UND College of Engineering and Mines to develop the protocols and process improvements to be used. Consulting expertise will be provided by Peter Woods from Ontario, Canada, Tony Roisen and Pat Moran from Minneapolis, Minnesota, and Chase Rickson from White Bear Lake, Minnesota, all of whom bring decades of industry knowledge and experience to this project.

Task 2.0 – Design, Modifications, and Fabrication of Additional Elf Units: UND and ELF will fabricate two commercial-scale ELF units, along with modifying and improving the existing prototypes to include the newly developed Fluid Life Particle Sensing Technology. Another important task during this phase will be to create quality control protocols. This work will satisfy the requirement of providing the Coyote and Leland Olds stations with the four units needed to demonstrate the technology. These teams will also develop best practices to ensure the development of process improvement documentation and ISO compliance standards.

Task 3.0 – Onsite Field Testing at Power Generation Stations: UND and ELF will package and transport the units to the Coyote and Leland Olds plants where they will be connected to the lubricant reservoirs for an initial 90-day test. Plant personnel will take a 250 m/l sample each week at pre-determined intervals for further lab analysis to compare to the ELF/Fluid Life real-time data. In addition, plant personnel will take readings from the ELF Fluid Life Particle Sensing Technology corresponding to the sample collection and add that information to a log, which will track the data associated with each sample. The samples will be sent to Fluid Life Labs, an internationally recognized laboratory, to analyze the samples for a side-by-side comparison to the particle sensor reading. The third-party lab will provide ISO certified results for wear metals, additives, viscosity, varnish potential, total acid number, and ISO particle numbers, or cleanliness codes, that are standard for oil analysis. This analysis will show the reliability of the new particle sensing technology to replace the previous method of sampling the lubricant and obtaining the lab results needed for managing the reservoir's cleanliness.

ELF filter elements will be removed after 45 days and at the completion of the onsite field testing. SEM and XRD analysis of the individual elements will be conducted to examine the amount and the nature of the material collected on the plates. In conjunction with real-time particle sensor data, this analysis will indicate the rate at which the plates will start to lose effectiveness due to particle buildup. In a conventional gas phase electrostatic precipitators (ESP), particles are continuously removed from the plates via rapping. When applying the ELF Technology as an on-line oil filter, particles will accumulate on the plates, and the filter element will be replaced periodically as the particles build up. This analysis will provide some indication of the required frequency of this routine maintenance. As a part of this evaluation, a plate from the inlet, middle, and exit of the unit will be examined. Prior experience with ESP indicates the inlet plates will remove the bulk of the particulates. As these plates become coated with particles and lose their effectiveness, the build-up from oil cleansing will continually move towards the exit plates in the filter. When the filter is first brought online with dirty oil in the reservoir, there will be a rapid build-up of particles on the filter plates, as expected. Once the filter has completed the initial cleaning, the particle loading from the ELF filters will be lower. A comparison of the 45-day and the 90-day filter conditions will provide evidence of the expected performance. The post-test SME/XRD work will provide an indication of how quickly the plates develop a build-up of particulates, which is another indication of the lifetime of the individual filters and will help develop a realistic maintenance cycle. SEM analysis will also provide any evidence of corrosive wear.

Samples of oil will be taken at the beginning, middle, and end of the test campaign. In addition to the testing done at the independent lab, the UND team will analyze the oil with specific interest on the type and size of particles in the oil. Evidence from previous work[1] indicates that electrostatic oil cleaners can remove micron-size particulate contaminants and polymerized oil oxidation products. This observation will be verified as part of the analysis planned for this project.

Task 4.0 Market Analysis and ISO Compliance of ELF: This task will include market analysis and ISO compliance pathways for the ELF technology. UND will help ELF develop the commercialization plan, including the economic benefit and value stream related to the North Dakota coal-fired power plant industry. The economic impact within the state of North Dakota includes the creation of new jobs, significant cost savings in plant maintenance, and increased local economic stimuli. ELF anticipates developing a North Dakota fabricating facility to meet market demand from power plants and implementation in other industries. UND will assemble and provide supporting documentation to ELF to achieve ISO compliance.

3.4 Anticipated Results

Results from this test program will demonstrate that the ELF technology is an effective method to improve the cleanliness of turbine oil as measured by the ISO 4406 particle number and varnish potential. This technology will significantly reduce the number of the submicron particulate contaminants and the polymerized oil oxidation products, something conventional filters cannot achieve. Results are also expected to demonstrate the design of the unit, such as the physical size, plate area, and other dimensions, which are well-matched with the size of the turbine reservoir and the expected particle loadings.

ELECTROSTATIC FILTRATION OF LARGE LUBRICANT RESERVOIRS

Once the tests outlined in the scope of work are completed, we anticipate the technology will be commercially-deployable, with subsequent adoption of the ELF technology by coal-fired power plants in North Dakota. The savings expected by adopting the ELF technology will be attractive and encourage the plants to include the novel technology into their turbine life-cycle maintenance budgets. Their investment will allow the reduction or elimination of the sampling and testing of the lubricating oil, increasing power generation during times usually dedicated to turbine maintenance. Adopting the ELF technology will significantly increase lubricant life, improve turbine performance, and allow for larger quantities of North Dakota lignite coal consumption.

After introducing the technology to the local North Dakota power community, ELF management will address the national power generation community. Making the technology available to a broader audience will increase the need for the product and increase the creation of jobs in North Dakota. ELF Technologies would establish a larger business footprint in North Dakota to support growth as the interest in their technology increases. The initial ELF plant will occupy approximately 10,000 sq. ft. and will employ ten North Dakota workers. The facility will be built near UND, allowing for student participation in flex-time work programs that complement their academic pursuits. This partnership ensures a continuous stream of qualified future employees that already have experience and training with ELF technology. ELF will, in turn, invest in several local industries, from manufacturers and fabricators to end-users.

While ELF has been working with UND on the initial "Proof of Concept," they have partnered extensively with Steffes Corp., Lunseth Plumbing & Heating Co., Tristeel Manufacturing Co., Red River Plumbing Supplies, Pro-Tec Powder Coating, and a host of other small businesses in the greater Grand Forks community. ELF will continue to pursue these business relationships as they work to bolster the local North Dakota economy.

The senior engineering class in the College of Engineering & Mines will benefit from the project's funding, with the opportunity to participate in yearly related design projects. This additional partnership with UND will provide industry-related experience to students while giving faculty the opportunity to engage ELF in designing low-cost process design improvements. The UND and ELF collaboration will attract students to the UND College of Engineering and Mines to develop unique technologies and provide student employment both before and after graduation.

3.5 Facilities and Resources

Fabrication Facilities (UND) – UND has a fully equipped fabrication facility which includes a complete list of opportunities, including welding, machining, electrical, and installation services. A majority of the fabrication of the new ELF units will be done in UND shops, while local contractors will be hired for any pieces that require ASTM certification.

Materials Characterization Lab (MCL, UND) – The MCL was established to support UND research and educational activities, industry research, sample analysis needs, and act as a regional satellite lab. It is supported by experienced technicians and analytical chemists with a vast array of equipment and capabilities, including SEM-EDX, ICP-MS, XRF, XRD, and thermal gravimetric analysis. Equipment from this lab will be used to examine the nature of the particles in the oil and to evaluate the particle deposition and buildup on the plates.

Environmental Analytical Research Laboratory (EARL, UND) – The EARL houses principal analytical instruments, including an ion chromatograph, atomic absorption spectrometer, a total organic carbon analyzer, sulfur analyzer, and ancillary equipment to support teaching, scientific research, and engineering design projects. This lab will be used to analyze the quality of the oil before and after the testing campaign.

3.6 Environmental and Economic Impacts During Project

The environmental impacts resulting from performing the proposed work are negligible. Waste streams produced as a result of this testing will be disposed of in conjunction with the UND Safety Office using existing waste disposal procedures currently in place at UND. Economic impacts include employment opportunities for UND research faculty, students, and support staff. In addition to the economic impacts within UND, this project has the opportunity to strengthen the Grand Forks, ND economy by directly involving local businesses in ELF's supply chain.

3.7 Technical and Economic Impacts of Proposed Technology

The technical and economic impacts of the proposed technology include, but are not limited to, increased plant efficiencies when burning North Dakota lignite coal and improved understandings of lubricant oil conditions. This understanding allows for more significant strategic decisions, such as identifying and mitigating component fatigue before catastrophic failure.

3.7.1 Technical and Economic - Private Sector Impacts

Currently, power plants routinely sample their turbine oil, and if the results yield contaminants that exceed the recommended level, the plant removes 10% of the lubricant reservoir and replaces it with new oil at the cost of between $15-22 per gallon. Reservoir size varies, but is generally within the range of 6,000-10,000 gallons; therefore, removing and replacing 10% of the oil will cost $9,000 to $22,000. The ELF Technology will eliminate the need for oil replacement between planned shutdowns, resulting in a savings in both the cost of oil and manpower required for the routine maintenance. In addition, many power generation facilities will eventually shut down the turbine, sometimes every few years, to remove all reservoir oil, manually strip off varnish, and refill the reservoir with new lubricant. The expense can then increase from $90,000 to $220,000, depending on turbine size and the current cost of oil. The old contaminated oil must then be disposed of as hazardous waste. A system that removes both sub-micron particles and polymerized oil oxidation products will result in the continuous circulation of clean oil, which is expected to leave the turbine relatively free of varnish buildup. This particle reduction will substantially reduce the costs associated with turbine maintenance.

The installation of the ELF Technology at $85,000 per unit, four units for a 2-turbine station, and at a cost of $300,000 in lost revenue due to plant maintenance, each plant can expect a Return on Investment (ROI) after two normally expected maintenance periods. Successful demonstration of the technology in a power plant setting with verification from trusted independent experts in the field will provide ELF with the credentials needed to attract customers from the utility sector. There are approximately 4,700 power generation stations in the United States, and approximately 30,000 globally, which have two to ten turbines each. Using a conservative estimate of four turbines per station, there are approximately 18,800 turbines in the USA alone. If ELF captures 3% of that market, they can expect to commission 564 units in the first three years: approximately 16 units produced each month.

The “Clean Coal Story” is equally compelling and can strengthen the dynamic partnership between ELF, UND, and the State of North Dakota. Every barrel of turbine lubricant filtered by ELF represents a like amount of lubricant that does not need to be disposed of, reducing the likelihood of a potential environmental hazard. Assuming there are 30,000 power generation plants globally, with four turbines each equipped with a 6,000-gallon reservoir, the disposal of an annual total of 720 million gallons of lubricant oil can be mitigated with ELF technologies.

3.8 PROJECT NEED

Reducing maintenance costs and potentially extending the lifetime and feasibility of coal-fired power plants is critical to improving the value chain of the North Dakota lignite energy industry. Each lignite coal-fired power plant has similar operational procedures; however, those procedures vary from plant to plant since their managers and operating technicians have developed them. Manufacturers of electrical generating turbines, such as General Electric, Siemens, and other companies, provide an ISO 4406:99 specification for lubrication oil to preserve the warranties for their systems and maintain operational integrity. This ISO code, which refers to the levels of contaminants at various micron sizes, is typically in the 17/16/13 range for new oil. The left number represents the smallest particle size at 4 microns, the middle number represents a particle size of 6 microns, and the right number represents a particle size of 14 microns. The numbers themselves represent the particle count as an exponent of 2, such as 2^x where x is the number given in the ISO code. Therefore, a change up to or down by one for the given numeric value represents an increase or decrease of 50%. Changing the value from 16 (on the left) to 15 means that the particle count, or the number of particles in that size range, has been reduced in the source fluid by 1/2. Similarly, an increase from 16 to 17 would mean the source stock saw the doubling of the number count for that particle size.

Operational staff receive a score of pass or fail for the condition of the the lubricating fluid when sampled and tested. This score means the lab will report either: 1) the oil is at or below the manufacturer's recommended level of contaminants, or 2) it exceeds the manufacturer's recommended level of contaminants. If the results yield a level of contaminants that exceed the recommended requirements, the plant removes 10% of the lubricant reservoir and replaces it with new lubricant oil at the cost of between $15-22 per gallon. Reservoir size varies, but is generally within the range of 6,000-10,000 gallons; therefore, removing and replacing 10% of the oil will cost $9,000 to $22,000. The oil condition test is repeated with lab results, which dictate further action.

Many power generation facilities will eventually shut down the turbine, sometimes every few years, to remove all reservoir oil, manually strip off varnish, and refill the reservoir with new lubricant. The cost can then increase to $90,000 to $220,000, depending on turbine size and the cost of the oil; in addition, the old contaminated oil must be disposed of as hazardous waste. The ELF unit's ability to remove polymerized oil oxidation products and allow for the continued use of ultra-clean oil will reduce or eliminate the deposition of varnish on turbine components. Bathing the turbine in clean oil is also expected to strip varnish from already coated surfaces.

The on-line real-time particle counter will allow the plant operators to continuously see the trends in oil quality, allowing for changes to be noticed immediately, using the technology as a diagnostic tool. The current ISO method will only alert the plant operator when a significant change in oil quality has occurred, such as a 2 to 4x change in the particle count, and only at intervals matching the plant's current sampling schedule, which could be months apart. Utilizing the ELF technology can extend lubricant life by providing a continuous stream of information to plant personnel, who will have real-time data and, therefore, know the exact condition of the oil. This stream of information will eliminate uncertainty and unnecessary sampling, testing, and down-time. Early problem detection can significantly reduce any cost of repairs and potential downtime.

Other industries, not only within the State of North Dakota but worldwide, will benefit from this technology; however, it will need to be demonstrated at full-scale to deploy successfully. The primary target market, the utility sector, is conservative and unlikely to implement an inadequately demonstrated technology. Independently verified results of technology demonstration lend further credence to the industry; therefore, one of the goals of this project will be to develop and establish ISO compliance for future testing of the ELF technology at additional North Dakota coal-fired power plants.

4. STANDARDS OF SUCCESS

The standards of success for the outcome of the proposed work are as follows:

- A successful trial at the Coyote and Leland Olds power stations will demonstrate the efficacy of the electrostatic lubricant filtration technology to improve the quality of the turbine oil to an ISO level at or below 16/14/11, the NAS 1638 standard for clean oil.
- Accurate and real-time particle sensor data validated against certified lab ISO 4406 data, allowing the plant to receive a continuous understanding of the condition of the lubricant oil without sampling or testing.
- The manufacture, fabrication, and deployment of two additional units to the Coyote and Leland Olds power stations, resulting in the incorporation of the technology into their existing maintenance regimens permanently.
- Developing a marketing plan and ascertaining ISO compliance, including the functional economic and financial models to evaluate feasibility and commercial prospects.

5. BACKGROUND INFORMATION

In conjunction with UND and the ND Department of Commerce project, ELF has demonstrated the ability to remove and filter turbine lubricants, showing promise for the economic and market-disruptive process.

ELECTROSTATIC FILTRATION OF LARGE LUBRICANT RESERVOIRS

5.1 Definition of the Research Problem/Opportunity

Every power plant creates steam to drive a turbine, which in turn creates electricity. That turbine has a continuous flow of oil needed to reduce friction, as friction is detrimental to turbine efficiency. As the turbine spins quickly, with many revolutions per minute, tiny contaminant particles are generated from the metal-on-metal action. These particles stick to the turbine's internal components, creating what is known as "Varnish Build-up." The ELF system removes contaminants, down to the sub-micron level, to allow the turbine to operate within ISO compliance. The resultant varnish would necessitate scheduled maintenance, and in some cases, cause catastrophic failure that can cause up to tens of millions of dollars in damages.

The typical operating oil condition is regulated and follows ISO 4406 standards based on the fluid cleanliness in particles per grams per liter. The scaling of ISO codes is not linear. The three numbers in the ISO code represent the particle counts at the 4-, 6-, and 14-micron size, with the actual number being the exponent of two that equates to the number of particles, such as 2^x, where x is the ISO number, and 2 raised to that power is the number of particles. Therefore, a reduction from 20/19/16 to 19/18/15 is a 50% reduction in particle count for each size. A visualization of the particle count in relation to the ISO Code is shown in Figure 1. Many power generation sites have an internal recommendation of which standard, or ISO fluid code, they must operate within. For the Leland Old's power station, the suggested maximum ISO code tolerance is 20/19/16.

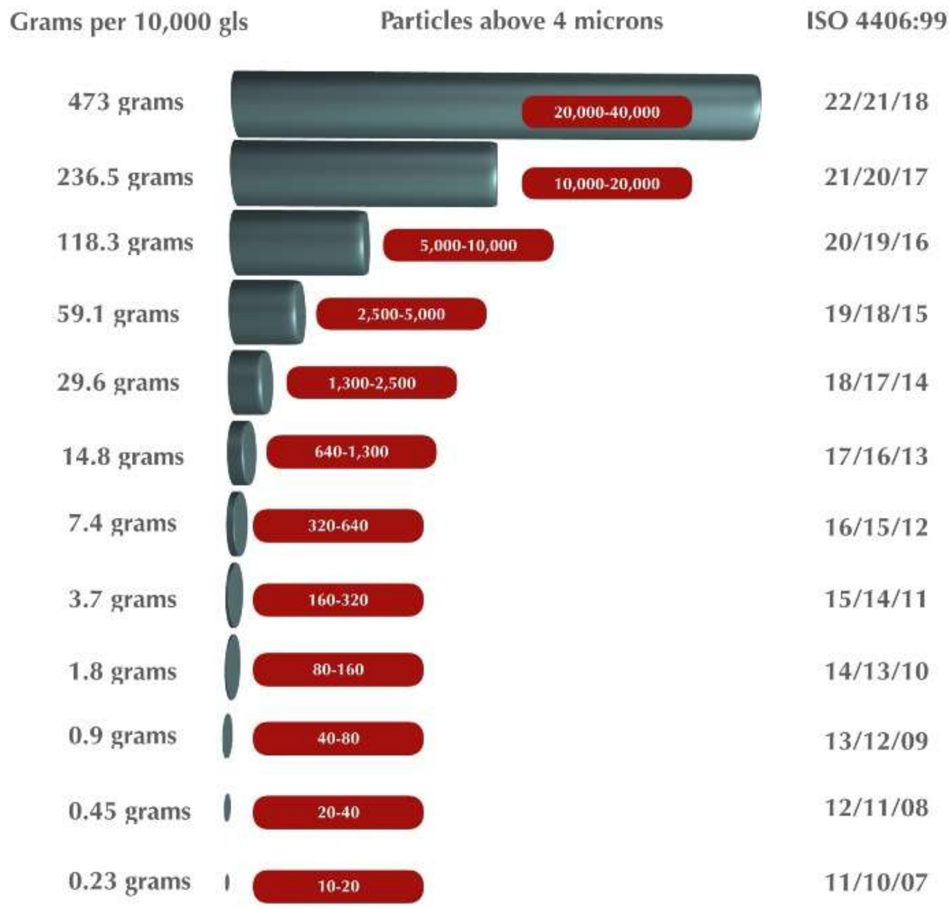

Figure 1: ISO Code 4406:99 Fluid Cleanliness

Eliminating varnish from the internal moving parts of turbines is a problem all power generation plants encounter. Laboratory tests of the source lubricants are conducted regularly by plant engineers to assess the ISO contaminant level and effectiveness of the lubricant oil. Once the level is determined, and the ISO contamination level has surpassed an acceptable level, the plant engineers have one of two options: 1) exchange a quantity of spent oil with new oil in an attempt to dilute it to an acceptable laboratory result, or 2) empty and dispose of the contaminated oil and replace entirely with new oil. When a turbine is emptied, many plants opt to open up the turbine and manually clean the parts, removing the varnish build-up. The opportunity cost of this downtime can exceed $300,000 per day, which stems from power not being generated during the maintenance period. This cost creates an opportunity for ELF to have a dynamic effect on plant operation efficiencies, revenue streams, and maintenance allocations. Furthermore, the ability to see trends in oil quality serves as an early indication of potential problems requiring maintenance actions.

5.2 Proposed Technology: Electrostatic Lubrication Filtration (ELF)

The Electrostatic Lubricant Filtration technology was an outgrowth of a decades-old development in the Electrostatic Air Filtration industry. Application of the electrostatic filter to remove contaminants in oil-based systems was reported by KLEENTEK Industrial Co, Ltd. in their 2002 paper to the National Fluid Power Association and Society of Automotive Engineers[1]. Their work shows that in the case of an oil-based system, the creation of electrostatic fields within the filter stacks charge metallic contaminants, which then draws the contaminants into a series of aluminum plates where they are permanently "welded," eliminating them from the source lubricant. When used in a circulating system, rather than the "once-through" operation of gas cleanup systems, oil filtration occurs on a 24-hour a day basis. This 24-hour filtration is essential, as the efficiency of the one-pass method in an oil-based system is low by conventional gas cleanup standards due to the dialectic properties and high viscosity of the oil. Since the oil is continuously recirculated, the cumulative effect of the relatively low removal efficiencies will eventually result in high overall collection efficiencies over time. The ELF apparatus will remove contaminants down to the molecular level, as is the case with their air filtration counterparts. Once the source liquid achieves a contaminant-free consistency, the fluid will begin to remove varnish build-up within the turbine and protect the internal mechanisms.

The ELF technology is a newly-developed Electrostatic Lubricant Filtration process to clean and filter oil at the sub-micron level. The system's design is based upon the fundamental equations governing electrostatic systems (see Appendix for details)[2]. The process involves a stainless steel canister housing 18 aluminum plates separated by a medium. These 18 plates provide a large collection area, which improves the overall efficiency and provides adequate surface area for the collection of particles, providing a longer life-time for the filter. When a large electric potential gradient is applied across the plates, an electrostatic field is generated. These fields attract positively charged contaminant particles in the oil and bind them to the aluminum plates, thereby efficiently removing them from the source lubricant.

The source lubricants will have a longer lifespan due to reducing the metal and polymerized oil oxidation contaminants. The ELF Technology can remove existing varnish buildup from the interior surfaces when added to a “dirty” turbine, allowing most maintenance activities to be reduced or eliminated. In a “clean” turbine situation, the ELF Technology is expected to eliminate or greatly reduce the varnish build-up on the turbine surfaces. Utilizing the ELF technology improves the bottom-line for power plants: the cost of replacing oil in a 6,000-gallon reservoir can exceed $150,000, coupled with the loss of as much as $300,000 from the lack of power production.

ELF will develop protocols that will be reviewed and approved by the UND team, which will ensure the validity of the demonstration. The UND team will travel to the host sites to review the protocols with the plant personnel. Establishing a chain of custody for the samples to ensure they are traced back to the plant where they were produced will be essential to guarantee accurate documentation of the dates and times of sampling. These samples will at no time be available to ELF, as they will be analyzed by an independent ISO 17025 certified lab, after which the results will be transmitted to UND for review before submission to ELF. The ELF team will document the demonstration results, which will be reviewed by the UND team and certified for accuracy before being released.

5.3 Preliminary Laboratory Scale Data

ELF Technologies recently completed two beta field tests, one at the Leland Olds Station and one at the Coyote Station, which are both lignite-fired electrical generating plants located in North Dakota as part of the North Dakota Department of Commerce project. The Coyote station plant has an oil reservoir size of 12,000 gallons and had starting particle counts of 9,030, 2,180, and 390 for the 4-, 6-, and 14-micron sizes, respectively. The Leland Olds plant has a 4,500-gallon oil reservoir and had starting particle counts of 1,250, 520, and 80 for the 4-, 6,- and 14-micron sizes, respectively. High removal efficiencies were obtained from both plants and had similar trends when plotted versus time, agreeing with our hypotheses (Figures 2 and 3). In both field tests, a reduction in particle counts to levels equivalent to fresh oil were obtained by the end of the testing cycle.

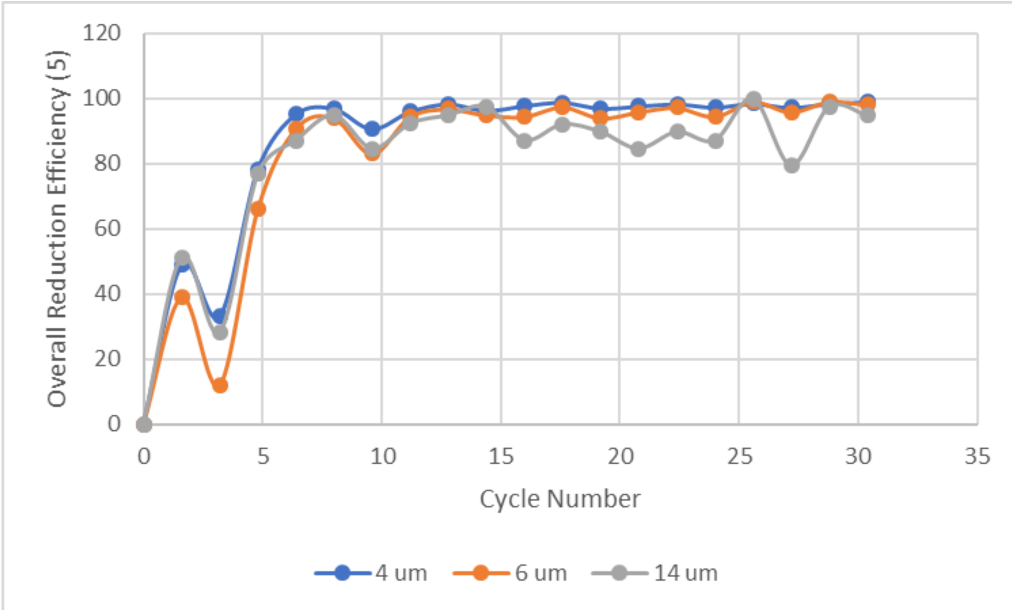

Figure 2. Reduction of particle counts for the field test at the Leland Olds Station

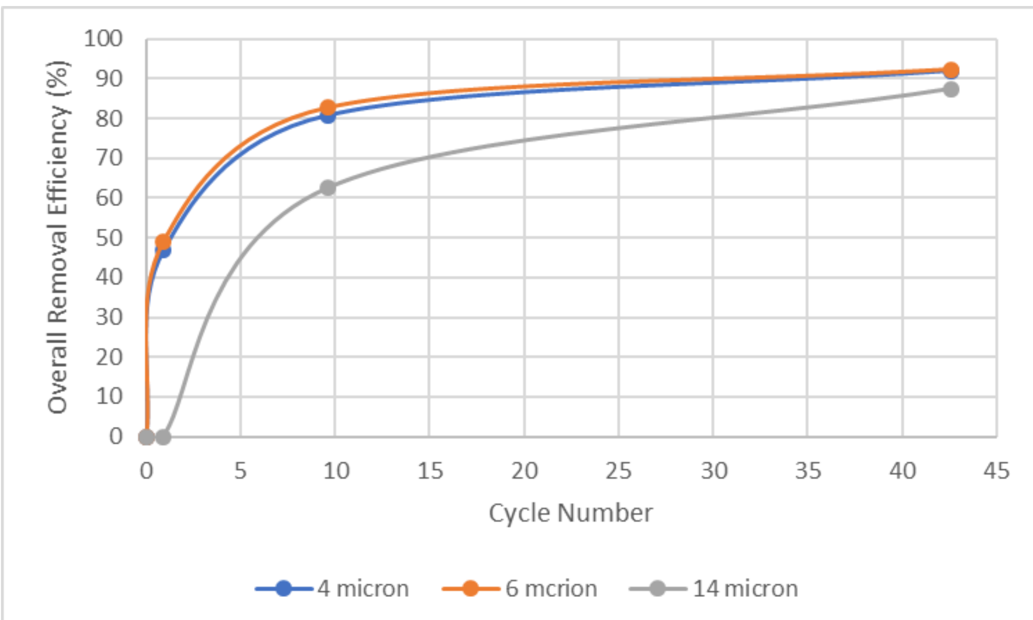

Figure 3. Reduction of particle counts for the field test at the Coyote Station

ELECTROSTATIC FILTRATION OF LARGE LUBRICANT RESERVOIRS

6. QUALIFICATIONS

UND Key Personnel: Mr. Nicholas Dyrstad-Cincotta, is an Engineer at UND's College of Engineering and Mines – Institute for Energy Studies (IES), and will be the PI. His research is primarily in the design, programming, and testing of energy production systems. His previous work involves rare earth element extraction, carbon capture, and chemical looping combustion. He has worked with IES for six years on various research projects, focusing on supercritical water desalination. He is on the professional engineer track and holds a B.S. and M.S. in Mechanical Engineering from UND. Under the guidance and expertise of Mr. Junior Nasah, he will serve as the PI for UND's scope of work, as described in the project work plan. He has experience with research in this area and has served as the technical lead on the prior development of the ELF project at UND.

Mr. Junior Nasah, Manager of Major Projects at UND IES, will serve as UND's Co-PI for the project. He has over ten years of experience in the areas of experimental bench units of advanced combustion systems, fluid-bed based technology development, and high-temperature applications. As the Co-PI, he will provide mentorship to Mr. Dyrstad-Cincotta and allocate resources required to complete the project successfully.

Mr. James Rickson, President & CEO of ELF, will be responsible for budgets, scheduling, purchasing, customer relations, sales, and the overall mission. Mr. Rickson will utilize his experience, current resources, and the comprehensive team he has assembled over the past decade to fulfill these responsibilities. This team includes:

- Chase Rickson, VP of Operations, who is primarily involved with process improvement and ISO compliance.
- Peter Woods, Chief Technical Officer, who has 25 years of experience in Electrostatic Lubrication Filtration.
- Tony Roisen and Pat Moran of Quality Stainless, who have 25 years of experience in manufacturing, cost controls, JIT, and supply chain management.
- Mickey Walsh, who has 30 years of experience in commercial industrial equipment sales.

- Dan Bicz, who has 20 years of experience with the Department of Defense and Military Industrial Complex.

7. VALUE TO NORTH DAKOTA

We estimate project completion after 12 months from the release date of the funding. The benefits realized directly by the North Dakota power generation community include:

1) Eliminating the requirement of removing and replacing turbine oil to achieve the manufacturer's recommended ISO compliance. Reservoir size varies, but is generally within the range of 6,000-10,000 gallons; therefore, eliminating the need to remove and replace 10% of the oil will save $9,000 to $22,000 per occurrence.
2) Ensuring the turbine is continuously operating with ISO compliant or cleaner oil reduces wear and tear on the turbine.
3) Decreasing unnecessary downtime and the associated cost of reduced power generation from the scheduled maintenance of an off-line turbine. The cost associated with turbine cleaning and oil replacement can range from $90,000 to $220,000, depending on turbine size and oil cost.
4) Saving plant personnel time by reducing the required sampling and lab testing.
5) Reducing costs associated with the acquisition and disposal of waste oil.

Further benefits to the State of North Dakota include the establishment of a new business in the state. Based upon the successful demonstration of the technology, ELF Technologies is proposing the establishment of a larger business footprint in North Dakota to support growth as interest in their technology increases. The initial ELF plant will occupy approximately 10,000 sq. ft. and will employ ten North Dakota workers. While ELF has been working with UND on the initial "Proof of Concept," they have partnered extensively with North Dakota based companies including Steffes Corp., Lunseth Plumbing & Heating Co., Tristeel Manufacturing Co., Red River Plumbing Supplies, Pro-Tec Powder Coating, and a host of other small businesses in the greater Grand Forks community. ELF will continue to pursue these business relationships as they work to bolster the local North Dakota economy.

8. MANAGEMENT

The UND Institute for Energy Studies (IES) and the Electrostatic Lubrication Filtration (ELF) company have assembled a team to perform the proposed work. This team will have the expertise required to develop the process by which the validity and marketability of the ELF unit will be assessed and implemented by power generation stations.

Mr. Nicholas Dyrstad-Cincotta will be the principal investigator and will be responsible for managing resources and schedules. He will also be responsible for coordinating all tasks within the UND IES and will ensure all personnel, equipment, and other resources will be made available to conduct the project efficiently. Mr. Junior Nasah will serve as the program manager, accepting responsibility for coordinating meetings with project participants or sponsors.

The project has been organized by task, with leads or team members accepting responsibility for the completion of each task. The UND IES will be responsible for overall project management, and with assistance from ELF, will direct the fabrication efforts of Task 2. ELF will be responsible for overseeing the communications and scheduling the field demonstrations in Task 3, with assistance from UND for transportation and hookups. UND will lead the market analysis and the establishment of ISO compliance in Task 4, with input from ELF.

Project meetings and conference calls with UND and the ELF team will be held on a bi-weekly basis to conduct project activities, review project timelines, evaluate upcoming milestones or deliverables, and discuss the costs and challenges associated with the completion of project tasks. Planning and review meetings or calls with the host sites will be held monthly to ensure the communication and discussion of accomplishments, plans, and risk management.

Intellectual property management and discussions have been initiated. During the course of the project, any new findings will be promptly documented, and patent applications will be filed to protect the intellectual property as necessary. Discussions with potential commercial sponsors have been initiated regarding the further development and scale-up of the technology and will be continued on a semi-annual basis as the project progresses.

9. TIMETABLE

The proposed project timeline is 12 months, with an estimated start date of February 1st, 2021. The project Gantt chart is displayed in Figure 4. Significant milestones and planned completion dates are provided in Table 1.

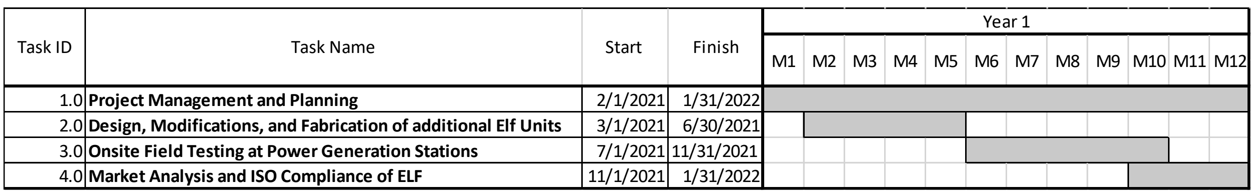

Figure 4: Project Gantt Chart

Table 1: Project Timing and Milestones

ID	Task Number	Description	Planned Completion Date	Actual Completion Date	Verification Method
A	1.0	Kick-off Meeting	2/28/2021		Presentation File
B	2.0	Update ELF Design & Model	3/31/2021		Quarterly Report
C	2.0	Elf Hardware and Components Budgeted/Purchased	4/15/2021		Quarterly Report
D	2.0	ELF Units Fabricated	6/30/2021		Task Report
E	3.0	On-Site Field Demonstrations Initiated	7/31/2021		Quarterly Report
F	3.0	On-Site Field Demo preliminary data analysis	9/15/2021		Quarterly Report
G	3.0	On-site Field Demo Completion	10/31/2021		Quarterly Report
H	3.0	Data Analysis and Summary Report	11/30/2021		Task Report
I	4.0	Market Analysis	1/31/2022		Task Report
J	4.0	Establish ISO Compliance	1/31/2022		Task Report
K	1.0	Final Technical Report	1/31/2022		Final Report

10. BUDGET

The following table summarizes the total project budget and the requested funding for each of the cost-share partners.

Budget Category	Total Project	ELF	NDIC	BEPC	OTPC
Personnel	$ 147,998	$ 91,250	$ 56,748	$ 0	$ 0
Travel	$ 18,849	$ 16,704	$ 2,145	$ 0	$ 0
Equipment	$ 85,000	$ 20,000	$ 65,000	$ 0	$ 0
Supplies	$ 5,000	$ 5,000	$ -	$ 0	$ 0
Subcontracts	$ 2,500	$ 2,500	$ -	$ 0	$ 0
Other Direct Costs	$ 2,450	$ -	$ 2,450	$ 20,000	$ 20,000
Indirect Cost	$ 50,150	$ 25,000	$ 25,151	$ 0	$ 0
Total cost	$ 351,948	$ 160,454	$ 151,494	$ 20,000	$ 20,000
Percent of Total	100	45.6%	43.0%	5.7%	5.7%

The total budget is $351,948. We are requesting $151,494 from the Lignite Research Council, matched by $160,545 in cash or equivalent. ELF will contribute time, travel, expertise, consulting specialists, land and buildings, utilities, specialized equipment, and cash. $20,000 from each of BEPC and OTPC will be added as in-kind for hosting the technology demonstrations, assisting installation, and sampling and analysis.

Personnel

Salary estimates are based on the scope of work. The labor rate used for specific personnel is based on their current salary rate. Generic labor categories have also been established with average labor rates. The table below gives the personnel cost breakdown. Any reference to hours worked on this grant is for budgeting purposes only. The University of North Dakota tracks employee’s time based on effort percentage and will not track or report employee’s time worked on this project in hours. Final numbers may differ due to rounding.

Fringe benefits are estimated for proposal purposes only. The true cost of each individual's fringe benefit plan will be charged to the project on award implementation. Fringe benefits are estimated based upon the current rates for each labor category.

Table 2: UND - IES Personnel Salary Including Fringe Benefits

Personnel	**Hours**	**Cost**
Nasah, Project Manager	32	$ 1,984
Nicholas Dyrstad-Cincotta, PI	580	$ 28,420
Research Engineer	520	$ 25,480
Resource Manager	32	$ 864
Total	**1164**	**$ 56,748**

Table 3: ELF Personnel Salary Including Fringe Benefits

Personnel	**Hours**	**Rate**	**Total**
James Rickson	500	$ 100.00	$ 50,000
Chase Rickson	250	$ 50.00	$ 12,500
Tony Roisen	100	$ 50.00	$ 5,000
Pat Moran	100	$ 50.00	$ 5,000
Mickey Walsh	250	$ 75.00	$ 18,750
Total			$ 91,250

Travel

A breakdown of travel is presented in the table below and includes travel to meetings and sampling field trips. Costs have been estimated based on available airfare and lodging rates, conference fees, standard per diem, and other UND travel policies. Estimates are broken down as follows:

Purpose of Travel	Depart From	Destination	No. of Days	No. of Travelers	Lodging per Traveler	Flight per Traveler	Vehicle per Traveler	Per Diem Per Traveler	Cost per Trip
Field Demo Start Leland Olds	Grand Forks, ND	Stanton, ND	1	1	0	0	$ 322	$ 35	$ 357
Field Demo Check Leland Olds	Grand Forks, ND	Stanton, ND	1	1	0	0	$ 322	$ 35	$ 357
Field Demo Final Leland Olds	Grand Forks, ND	Stanton, ND	1	1	0	0	$ 322	$ 35	$ 357
Field Demo Start Coyote Station	Grand Forks, ND	Buela, ND	1	1	0	0	$ 322	$ 35	$ 357
Field Demo Check Coyote Station	Grand Forks, ND	Buela, ND	1	1	0	0	$ 322	$ 35	$ 357
Field Demo Final Coyote Station	Grand Forks, ND	Buela, ND	1	1	0	0	$ 322	$ 35	$ 357

Equipment

Two additional ELF units are required to complete the scope of work. Cost is based on the prior market rate for materials of construction and assembly. At the end of the project, ownership of the equipment will be transferred to ELF Technology, LLC.

Equipment Item	Quantity	Unit Cost	Total Cost	Basis of Cost	Justification of Need
ELF Unit	2	$ 32,500.00	$ 65,000.00	Based on prior market rates for existing units	Required for full capacity field demonstrations
Total Equipment Cost			$ 65,000.00		

Subcontract

No subcontractors to NDIC funding planned.

Indirect Costs

The indirect cost rate included in this proposal is the federally approved rate for UND at 41%. The indirect cost method is the Modified Total Direct Cost method, defined as the total direct cost of the project minus equipment in excess of $5,000, or the first $25,000 of each subcontract in excess of this value, including tuition remission and in-kind cost-share contributions.

11. MATCHING FUNDS

A breakdown of the funding sources for the project is provided in Table 2.

Table 4: Matching funds and funding breakdown by support source

Support Source	Cash	In-Kind	Total	% of Project
NDIC	$ 151,494	0	$ 151,494	43.0%
ELF	0	$ 160,454	$ 160,454	45.6%
BEPC	0	$20,000	$20,000	5.7%
OTPC	0	$20,000	$20,000	5.7%
TOTAL			**$ 351,948**	**100%**

12. TAX LIABILITY

No outstanding tax liabilities to the state of North Dakota.

13. CONFIDENTIAL INFORMATION

United States Patent Office, patent number 15/894,167

14. REFERENCES

1. Sasaki, A. and Uchigama, S., A New Technology for Oil Management: Electrostatic Oil Cleaner, in *National Fluid Power Association and Society of Automotive Engineer, Inc.*, pp. 9-18, 2002.

2. Kahn, S. and Dyrstad-Cincotta, N., Governing Equations for the ELF Technology Electrostatic Filtration, Concept Paper, 2020.

15. APPENDICES

ELECTROSTATIC FILTRATION OF LARGE LUBRICANT RESERVOIRS

15.1 Governing Equations for the ELF Technology: Electrostatic Filtration

GOVERNING EQUATIONS FOR THE ELF TECHNOLOGY ELECTROSTATIC FILTRATION

Prepared for

ELF Technologies

Prepared by

Shabaz Kahn

Nicholas Dyrstad-Cincotta

Institute for Energy Studies

University of North Dakota

August 10, 2020

GOVERNING EQUATIONS FOR THE ELF TECHNOLOGY ELECTROSTATIC FILTRATION

The principal action of the ELF Technology electrostatic filtration is the charging of dust particles and forcing these particles to the collecting plate. The technology can be modeled using mathematical operations which are developed from currently existing traditional electrostatic precipitators. A number of assumptions were made to understand the theory behind ELF. The simplified design, underlying mathematical equations, assumptions, and calculations are discussed in this paper.

ELF Design

Figure 1 represents a simplified schematic of the ELF unit set-up, where positive and negative electrodes (collection plates) are stacked in alternating fashion. Figure 2 represents the corona onset and working zone for a typical electrostatic set-up.

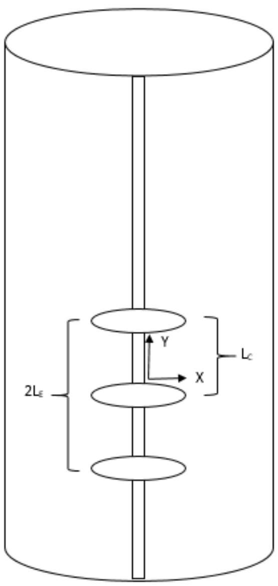

Figure 1: ELF Unit Schematic
L_E= Emitter Electrode Distance
L_C= Collector Electrode Distance

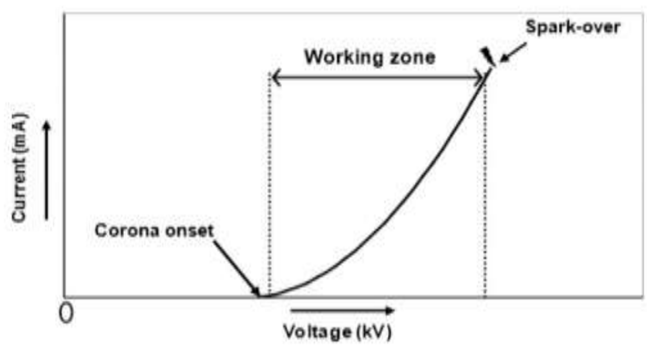

Figure 2: Typical current-voltage curve [1]

The ELF unit functions by having negatively charged emitter plate and positive charged collector plates separated by a nominal distance. Each negative and positive plate is insulated from one another with a layer of foam. Negative voltage is applied, creating a corona field, causing the particles surrounding the plate to form a negative charge. The negative charged particles are then extremely attracted to the positive plate, where they migrate and effectively bond to. Each of aspect will be looked at in closer detail in the following sections.

Background

The Dielectric strength of transformer oil is also known as the breakdown voltage. “Breakdown Voltage” (BDV) is measured by observing the voltage that is required to jump a spark between two electrodes immersed in the oil separated by a specific gap or distance. Also known as the sparking strength, the higher the voltage required to jump the spark, the higher the BDV will be in the oil. The lower the voltage required to jump the spark, the BDV will be lower indicating the presence of moisture content and other conducting substances in the oil [2].

The dielectric strength of transformer oil is very important since it is essential in maintaining the reliable operation of high-voltage power transformers. The dielectric strength of transformer oil is impacted by the presence of acids, water, and other contaminates. The Dielectric strength of oil is extremely sensitive to hydration or introduction of water and moisture. Under the action of the electric field of the emulsified oil, droplets of water are drawn to places where the field strength is particularly high. This process begins the process of oil breakdown. Clean oil with a low moisture content gives higher BDV results than oil with high moisture content and other conducting impurities.

1. Corona and Electrostatic Precipitation

The voltage applied to the electrodes causes the gas between the electrodes to break down electrically, an action known as a "corona." The electrodes usually are given a negative polarity because a negative corona supports a higher voltage than a positive corona before sparking occurs. The ions generated in the corona follow electric field lines from the wires to the collecting plates. Therefore, each wire establishes a charging zone through which the particles must pass.

The word "corona" has been used here as a general term which includes any repetitive short-time charge transfer, such as charge injection from electrodes, creepage discharges along dielectric surfaces, and the limited gas-phase discharges often called "partial discharge-PD." It does not include conventional ionic or electron mobility. Moreover, corona degradation may in itself lead to voltage breakdown without thermal runaway. Corona can be divided broadly into three types:

1) Directly from an electrode into the surrounding space (usually gas);
2) At the surface of a solid dielectric;
3) Within the volume of a solid dielectric (usually in a 4' void).

Corona can be characterized as a localized voltage breakdown which takes place repetitively. In the simplest case with an alternating voltage, a single discharge takes place on each halfcycle (or even on every other half-cycle). Usually, however, multiple discharges take place. With corona from an electrode into a gas, the repetition rate of the discharges increases with voltage (above an onset voltage, the corona start voltage - CSV). The repetition rate and magnitude are usually high and quite constant with time unless the characteristics of the electrode are changed by the corona. For surface and especially for volume corona, the characteristics of the dielectric solid may greatly influence both the corona repetition rate and magnitude as a function of time.

2. Electrical Operating Point and Collection Efficiency

The electrical operating point of an ESP section is the value of voltage and current at which the section operates. The best collection typically occurs when the highest electric field is present, which roughly corresponds to the highest voltage on the electrodes. The corona inception voltage is the lowest voltage necessary for the formation of a corona – the electrical discharge that produces ions for charging particles. The corona inception voltage decreases as the frequency of the applied voltage increases.

The charged dust particles are accelerated towards the collecting electrode by means of the Coulomb force within the electric field. According to the equation of motion, they reach a theoretical migration velocity that is dependent on the particle size. For comparatively large particles, that is, greater than 2 μm in diameter, the migration velocity is proportional to the electric field strength squared. For smaller particles the relationship is only linear. The so-called ''Deutsch'' equation states that a higher migration velocity leads to higher collection efficiency. However, it is actually influenced by many factors such as electrode geometry and properties of dust particles. It is also important to take into account that the effective migration velocity within a precipitator is not equal to the theoretical migration velocity that can be calculated. Thus, there is empiricism involved in modification of the original ''Deutsch'' equation in order to obtain more precise tools for the dimensioning of ESPs. From the power supply point of view, however, it can be stated that in general the collection efficiency is proportional to the applied voltage, VESP, squared and the precipitator current IESP [3].

In order to obtain higher collection efficiencies, it is important to operate the precipitator at a voltage as high as possible and also to provide enough power to drive a sufficiently high corona current [3]. Filtration speed is increased with increasing number of projections, applied voltage and oil temperature and with decreasing electrode spacing.

3. Investigation into Dielectric Breakdown Voltage of Insulating Oil

A dielectric breakdown voltage test is a measure of the electrical stress that an oil can withstand without breakdown. The test can be performed by using a test vessel with two electrodes mounted in it, with a fixed gap between them. Sample oil is placed in the vessel and an AC voltage is applied to the electrodes. The voltage is increased until the oil breaks down, i.e. until a spark passes between the electrodes. The test method for determining the breakdown voltage can vary based on the size and shape of the electrodes, the gap between them, the rate at which voltage is increased, and whether or not the oil is stirred during the test. A company that specializes in power applications, like Megger, can be utilized to procure standardized test equipment if it is desired to determine the exact dielectric constant of various new and used oils [4].

The theoretical dielectric strength of a specific material is an intrinsic property based off the bulk material and is independent of the configuration of the material or electrodes with which the field is applied. Because of defects in the dielectric materials, the dielectric strength is typically significantly less than the intrinsic strength of an ideal, defect free material. As shown in Table 1 (pulled from CRC handbook of chemistry and physics), the intrinsic value for dielectric strength of pure silicon oil is theoretically 10-15 kV/mm.

Table 1: Dielectric Strength of Liquids [5]

Material	Dielectric strength kV/mm	Ref.
Helium, He, liquid, 4.2 K	10	9
Static	10	11
Dynamic	5	11
	23	12
Nitrogen, N_2, liquid, 77K		
Coaxial cylinder electrodes	20	10
Sphere to plane electrodes	60	10
Water, H_2O, distilled	65-70	13
Carbon tetrachloride, CCl_4	5.5	14
	16.0	15
Hexane, C_6H_{14}	42.0	16
Two 2.54 cm diameter spherical electrodes, 50.8 μm space	156	17,18
Cyclohexane, C_6H_{12}	42-48	16
2-Methylpentane, C_6H_{14}	149	17,18
2,2-Dimethylbutane, C_6H_{14}	133	17,18
2,3-Dimethylbutane, C_6H_{14}	138	17,18
Benzene, C_6H_6	163	17,18
Chlorobenzene, C_6H_5Cl	7.1	14
	18.8	15
2,2,4-Trimethylpentane, C_8H_{18}	140	17,18
Phenylxylylethane	23.6	19
Heptane, C_7H_{16}	166	17,18
2,4-Dimethylpentane, C_7H_{16}	133	17,18
Toluene, $C_6H_5CH_3$	199	17,18
	46	16
	12.0	14
	20.4	15
Octane, C_8H_{18}	16.6	14
	20.4	15
	179	17,18
Ethylbenzene, C_8H_{10}	226	17,18
Propylbenzene, C_9H_{12}	250	17,18
Isopropylbenzene, C_9H_{12}	238	17,18
Decane, $C_{10}H_{22}$	192	17,18
Synthetic Paraffin Mixture		
Synfluid 2cSt PAO	29.5	37
Butylbenzene, $C_{10}H_{14}$	275	17,18
Isobutylbenzene, $C_{10}H_{14}$	222	17,18
Silicone oils—polydimethylsiloxanes, $(CH_3)_3Si\text{-}O\text{-}[Si(CH_3)_2]_x\text{-}O\text{-}Si(CH_3)_3$		
Polydimethylsiloxane silicone fluid	15.4	20
Dimethyl silicone	24.0	21,22
Phenylmethyl silicone	23.2	22
Silicone oil, Basilone M50	10-15	23
Mineral insulating oils	11.8	6
Polybutene oil for capacitors	13.8	6
Transformer dielectric liquid	28-30	6
Isopropylbiphenyl capacitor oil	23.6	6
Transformer oil	110.7	24
Transformer oil Agip ITE 360	9-12.6	23
Perfluorinated hydrocarbons		
Fluorinert FC 6001	8.0	23
Fluorinert FC 77	10.7	23
Perfluorinated polyethers		
Galden XAD (Mol. wt. 800)	10.5	23
Galden D40 (Mol. wt. 2000)	10.2	23
Castor oil	65	25

Experimental testing performed by Lee et al. found the dielectric breakdown voltage of pure transformer oil (OT-4) is about 10 kV with a gap distance of 1 mm between electrodes and 14 kV for a gap distance of 2.5mm [2]. Prior experimental testing with the Electrostatic Lubricant Filtration (ELF) unit yielded a breakdown voltage of 18kV at a gap distance of 1" (25.4mm).

Governing Equations

The operation of the ELF system can by understood by exploring three key processes:

1. Corona Development
2. Particle Charging
3. Collection efficiency

Corona Development: The key electrical control points for the ELF technology are Voltage and Current. The strength of the corona field depends primarily on these electrical operating set-points. The optimal collection occurs when the highest electric field is present, which roughly corresponds to the highest voltage on the electrodes [6]. The lowest voltage acceptable is the voltage required for the formation of the corona. This applied voltage and current, is divided into several parts:

1. Corona onset field at the emitter electrode surface
2. Corona onset voltage
3. Current Density
4. Sparking field strength

Corona Onset Field: The theoretical corona onset filed is calculated through Peek's formula as expressed in Equation (1)[7] :

$$E_c = 3 \times 10^6 f \left[s.g + 0.03 \sqrt{\frac{s.g}{r_c}} \right] \quad (1)$$

E_c = corona onset field at the emitter electrode surface, (V/m)
s.g.= specific gravity of the gas/liquid, relative to air at 293 K and 1 atm
r_c = radius of the wire, m
f = roughness factor (for a clean smooth wire/electrode =1.0; for practical applications= 0.6 is a reasonable value)

Corona Onset Voltage: The voltage that must be applied to the wire to obtain onset field strength is found by integrating the electric field from the wire to the collecting electrode. In cylindrical geometry, the field is inversely proportional to the radial distance. This leads to a logarithmic dependence of voltage on electrode dimensions. The corona onset voltage, V_0, is given by

$$V_0 = E_c r_c \ln\left(\frac{d}{r_c}\right) \quad (2)$$

d = outer cylinder radius in a tubular ELF
d = $(4/\pi)L_c$ for plate-wire ELF
L_c= Emitter Electrode-Collector Electrode Distance

The first electrode is charged to a very high negative voltage. As particles present in the fluid move past the negatively charged plate, they pick up a negative charge. Higher up the vessel (or further along, if it's a horizontal vessel), there's a second electrode consisting of metal plates charged to a high positive voltage and connected to ground. Since unlike charges attract, the negatively charged particles are attracted and collect to the positively charged plates [8].

Current Density: Until voltage reaches the corona onset voltage, current doesn't flow. The vertical electric field strength distribution from the Emitter plate to collector plate can be represented as:

If particle space charge present:

$$E_y(y) = \sqrt{(E'^2_{ave} + \frac{2J_p}{\epsilon_0 Z_i} y)} - E'_{ave} \quad (3)$$

If particle space charge is absent:

$$E_y(y) = \sqrt{(E'^2_{ave} + \frac{2J_p}{\epsilon_0\, Z_i} y)} \quad (4)$$

E'_{ave} = Average electrostatic field at plate ($\frac{V}{m}$)
J_p = The average current density at plate ($\frac{V}{m}$)
Z_i = The ion mobility ($\frac{m^2}{V/s}$)
ϵ_0 = Permittivity of space ($\frac{C^2}{N/m^2}$)
y = Distance from centerline

Cooperman and White [Reference number] provided two equations based electrostatic field and space charge field strength. From there, which equation to use is based on the assumption of the existence of a particle space charge and whether the electrostatic field is uniform.

Without Particle Space Charge

From the Poisson equation we know,

$$\nabla^2 V = \frac{dE}{dx} = \frac{\rho}{\epsilon_0} = -\frac{J_p}{\epsilon_0 Z_i E} \quad (5)$$

This yields,

$$E_y^2(y) = E'^2_{ave} + \frac{2J_p}{\epsilon_0 Z_i} y \quad (6)$$

E'_{ave} is the average electrostatic field and can be determined from Gauss Law to be,

$$E'_{ave} = \frac{\pi r_c E_c}{2L_E} \quad (7)$$

$$= \frac{\pi V_c}{2L_E \ln \frac{r_{cylinder}}{r_{emitter\ electrode}}} \quad (8)$$

The voltage that must be applied to the wire to obtain this value of field is found by integrating the electric field from the wire to the collecting electrode.

$$\int_0^{L_c} E_y dy = V \quad (9)$$

$$\int_0^{L_c} E_y dy = (V - V_c) + V_c \quad (10)$$

However, the formula for E_y was derived under the assumption that system had a uniform electrostatic fieldE'_{ave}. Hence, to maintain the consistency of the approximation, the second term $V_c$which represents the electrostatic voltage, must be replaced by$L_c E'_{ave}$.

$$(V - V_c) + L_c E'_{ave} = \int_0^{Lc} E_y dy$$

$$=> (V - V_c) + L_c E'_{ave} = \int_0^{L_c} \sqrt{E'^2_{ave} + \frac{2J_p}{\epsilon_0 Z_i} y}\, \mathrm{dy}$$

$$=> (V - V_c) + L_c E'_{ave} = \frac{Z_i \epsilon_o}{2J_p} . \frac{2}{3} \left[\left(E'_{ave} + \frac{2J_p}{\epsilon_0 Z_i} L_c\right)^{\frac{3}{2}} - E'^3_{ave}\right]$$

$$=> J_p = \frac{\epsilon_0 Z_i}{16 L_c} [\alpha + \sqrt{\alpha^2 + 192(V - V_c)(L_c E'_{ave})^3}], \quad (11)$$

Where:

$\alpha = 9(V - V_c + L_c E'_{ave})^2 - 12(L_c E'_{ave})^2$

$$E'_{ave} = \frac{\pi V_c}{2 L_E \ln \frac{r_{cylinder}}{r_{emitter\ electrode}}}$$

r_c = Radius of the discharge/emitter electrode

L_E = Emitter electrode-Emitter electrode distance

E_c = Corona initiating electric field ($\frac{V}{m}$)

V_c = Corona onset voltage (V)

L_c = Emitter electrode-Collector electrode distance

V = Applied voltage (V)

$r_{cylinder}$ = Cylinder radius

With Particle Space Charge

Then,

$$\frac{dE}{dy} = \frac{J_p}{\epsilon_0 Z_i E} + \frac{\rho}{\epsilon_0}$$

The solution for this is,

$$E_y - \frac{J_p}{\rho Z_i} \ln\left(1 + \frac{\rho Z_i}{J_p} E_y\right) = \frac{\rho}{\epsilon_0} y + E'_{ave} - \frac{J_p}{\rho Z_i}\left(1 + \frac{\rho Z_i}{J_p} E'_{ave}\right) \quad (12)$$

If E_y is the function of J_p and y,

Then,

$$V - V'_c + L_c E'_{ave} + \frac{L_c^2 \rho}{2\epsilon_0} = \int_0^{L_c} E_y dy$$

Here,

$$V'_c = V_c + \frac{L_c^2 \rho}{2\epsilon_0}$$

Where,

ρ = Dust space charge density

Sparking Field Strength:

$$E_s = 6.3 \times 10^5 (\frac{273P}{T})^{0.8}$$

Where,

E_s = Sparking field strength ($\frac{V}{m}$)

T = Absolute temperature, (K)

P = Gas pressure (atm)

Particle Charge:

Charging of particles takes place when ions collect on the surface of a particle. Once an ion is close to a particle, it is tightly bound because of the image charge within the particle. The image charge is a representation of the charge distortion that occurs when a real charge approaches a conducting surface. The distortion is equivalent to a charge of opposite magnitude to the real one, located as far below the surface as the real charge is above it. The motion of the fictitious charge is similar to the motion of an image in a mirror, hence the name. As more ions accumulate on a particle, the total charge tends to prevent further ionic bombardment.

There are two principal charging mechanisms: diffusion charging and field charging. Diffusion charging results from the thermal kinetic energy of the ions overcoming the repulsion of the ions already on the particle. Field charging results when ions follow electric field lines until they terminate on a particle. In general, both mechanisms operate for all sizes of particles. Field charging is the dominant mechanism for particles greater than about $2\mu m$, whereas diffusion charging dominates for particles smaller than about $0.5\mu m$ [5].

The particle charge is a function of particle size and can be described by Cochet's charge equation,

$$q = [\,(1+\frac{2\omega_i}{d_p})^2 + \frac{2}{1+\frac{2\omega_i}{d_p}} \times \frac{k-1}{k+2}\,]\,\pi\epsilon_0 E'_{ave} d_p^2 \qquad (13)$$

Where,

ω_i = Mean free path of the ion
d_p = Particle diameter
k = Dielectric constant of particles
E'_{ave} = Average electric field
ϵ_0 = Permittivity of the free space

Fine particle charge: For fine particles much smaller than the ionic mean free path ($\frac{\omega_i}{d_p} \gg 1$), second term of the equation can be neglected. The positive charge equation:

$$q_f = (1+\frac{2\omega_i}{d_p})^2\,\pi\epsilon_0 E'_{ave} d_p^2$$

A further simplification can made by approximating $(1+\frac{2\omega_i}{d_p})^2$ to $\frac{2\omega_i}{d_p}$,

$$q_f = 4\omega_i^2\,\pi\epsilon_0 E'_{ave} \qquad (14)$$

Coarse particle charge: For coarse particles much larger than the ionic mean free path ($\frac{\omega_i}{d_p} \gg 1$), the value $\frac{2\omega_i}{d_p}$ will be removed from first and second terms, the particle charge equation,

$$q_c = (2 \times \frac{k-1}{k+2})\,\pi\epsilon_0 E'_{ave} d_p^2 \qquad (15)$$

The total particle charge: The particle charge in terms of particle volume (v) over the entire particle size spectrum is a combination of two equations (14) and (15),

$$q = q_f + \frac{q_c}{v^{\frac{2}{3}}}$$

$$q = 4\omega_i^2\,\pi\epsilon_0 E'_{ave} + \left(2 \times \frac{k-1}{k+2}\right)\pi\epsilon_0 E'_{ave} d_p^2\,(\frac{6}{\pi})^{\frac{2}{3}} \qquad (16)$$

We know, effective migration velocity of a particle is,

$$V_e = \frac{qE_cC}{3\pi\mu d_p}$$

$$= \frac{[4\omega_i^2\,\pi\epsilon_0 E'_{ave} + \left(2 \times \frac{k-1}{k+2}\right)\pi\epsilon_0 E'_{ave} d_p^2\,(\frac{6}{\pi})^{\frac{2}{3}}\,]\,(\mathrm{C} + 3.314\,\frac{\omega}{d_p})\,E'_{ave}}{3\pi\mu d_p} \qquad (17)$$

Where,

$$C = C^* + 3.314\,\frac{\omega}{d_p} \quad [\,if\ \frac{\omega}{d_p} > 1, then\ C^* = 0.56$$

$$if\ \frac{\omega}{d_p}\ \le 1, then\ C^* = 1]$$

ω = Mean free path of gas

Collection Efficiency:

$$n = 1 - Exp\,(-\frac{A_c V_e}{Q})$$

Where,

Q = Volumetric flow rate of liquid
A_c = Specific collection surface area
V_e = Effective migration velocity

Applied Calculations

Corona onset field:

$$E_c = 3 \times 10^6 f \left[s.g + 0.03 \sqrt{\frac{s.g}{r_c}} \right]$$

$$= 2.15 \times 10^6\ V/m$$

Corona onset voltage:

d = outer cylinder radius in a tubular ELF, m	.3
E_c = corona onset field at the emitter electrode surface, (V/m)	2.15×10^6
r_c = radius of the emitter electrode, m	0.2873
V_c = corona onset voltage (V)	

$$V_c = E_c r_c \ln\left(\frac{d}{r_c}\right)$$

$$= 26{,}720\ \text{V}$$

Current density for non-uniform electrostatic field:

V_c = corona onset voltage (V)	26720
V = Applied voltage (V)	30000

ϵ_0 = Permittivity of space ($\frac{C^2}{N/m^2}$)	8.85×10^{-12}
Z_i = The ion mobility ($\frac{m^2}{V/s}$)	1.7×10^{-4}
J_p = The average current density at plate ($\frac{A}{m^2}$)	
L_c= Emitter Electrode-Collector Electrode Distance (m)	0.0127

$$J_p = \frac{9\epsilon_0 Z_i}{8{L_c}^3}(V - V_c)^2$$

$$= 8.9 \times 10^{-3}\ \frac{A}{m^2}$$

Sparking field strength:

P = Gas pressure (atm)	0.68
T = Absolute temperature, (K)	298
E_s = Sparking field strength ($\frac{V}{m}$)	

$$E_s = 6.3 \times 10^5 (\frac{273P}{T})^{0.8}$$

$$= 431{,}424\ \frac{V}{m}$$

Average electric field:

E_s = Sparking field strength ($\frac{V}{m}$)	431,424
K= Constant behave base on back corona	If severe back corona then value 2.50 and no back corona then 1.75

$$E'_{ave} = \frac{E_s}{K}$$

$$= 246528.28\ \frac{V}{m}$$

Total particle charge:

ω_i = Mean free path of the ion (m)	9.71×10^{-8}

d_p = Particle diameter (micron)	2.5×10^{-6}
k = Dielectric constant of particles	2.1
E'_{ave} = Average electric field, V	246,528
ϵ_0 = Permittivity of space ($\frac{C^2}{N/m^2}$)	8.85×10^{-12}
q= Particle charge (C)	

$$q = 4\omega_i^2\,\pi\epsilon_0 E'_{ave} + \left(2\times\frac{k-1}{k+2}\right)\pi\epsilon_0 E'_{ave} d_p^2\,(\frac{6}{\pi})^{\frac{2}{3}}$$

= 3.57×10^{-17} C

Effective migration velocity of a particle:

q= Particle charge (C)	3.57×10^{-17}
E_c = corona onset field at the emitter electrode surface, (V/m)	$2.15\times 10^6\ V/m$
Cn= Cunninghum Correction $Cn = C^* + 3.314\,\frac{\omega}{d_p}\ [if\ \frac{\omega}{d_p} > 1, then\ C^* = 0.56\ if\ \frac{\omega}{d_p} \leq 1, then\ C^* = 1]$ ω = Mean free path of gas	1.13
μ= Flow viscosity (kg/m.s)	1.3×10^{-1}
d_p = Particle diameter (micron)	2.5×10^{-6}
V_e = Particle migration velocity (m/s)	

$$V_e = \frac{qE_cCn}{3\pi\mu d_p}$$

= 2.83×10^{-5} ($\frac{m}{s}$)

Collection Efficiency:

Q = Volumetric flow rate of liquid ($\frac{m^3}{s}$)	5 gallon pre minute = 0.00032 cubic meter per second
A_c = Specific collection surface area (m^2)	0.122 square meter (2 collector plate of 11" in diameter)
V_e = Effective migration velocity (m/s)	2.83×10^{-5}
n= efficiency	

$$n = \left[1 - Exp\left(-\frac{A_cV_e}{Q}\right)\right] * 100$$

= 1.03% for 2.5 micron particles and a single plate set

Predicted Performance as a Function of Design

The basis for the above calculation is a particle diameter of 2.5 microns and a two-plate collection area. This serves as a basis to explore different design parameters and operational inputs. The following section provides additional insight on how the overall collection is impacted by the particle size of the contaminant, the number of plates (area) in the system, and the number of cycles (to approximate the impact of the oil reservoir size versus the circulation rate through the ELF filter).

Figure 3 shows the relative impact of the impurity particle size on the single pass collection efficiency, where the single pass efficiency is defined as the percentage of particles of any given size removed with one pass of the oil through the filter. This would represent the case where the oil was cleaned and sent to a separate storage tank, rather than contuously recirculating the oil back into the primary reservoir. The case where the oil is recirculated will be discussed later as related to the number of cycles.

Figure 3 shows that for particles 4, 6, 14, 25, 38 and 70 micron in size and same collection area, as the particle size increases the collection efficiency also increases. This is expected based upon theory and is observed in electrostatic filtration devices. This comparison is based upon the single-pass efficiency, and is meant to illustrate the impact of particle size rather than imply the absolute removal that can be expected from the ELF filter.

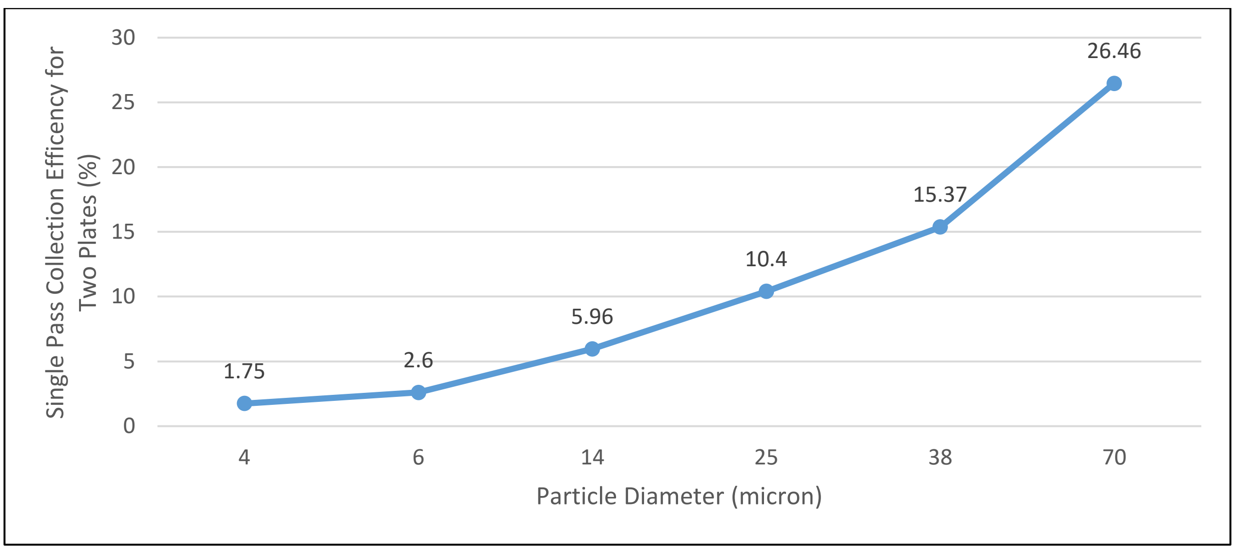

Figure 3: Single pass collection efficiency for two plates (%) versus Particle Diameter (micron)

The importance of the overall area of the collection plates is illustrated in the equation used to calculate the system efficiency. This observation is important because design of the ELF filter is modular, and the collection area can be easily increased during the design simply by increasing the number of plates inside the filter housing. Figure 4 compares the single pass collection efficiency for six particle sized and for multiple plate-sets ranging from 1 to 9. As expected, for single pass, the highest number of collection plates (maximum area) results in maximum number of the particles, and as shown before, the larger sized particles are collected at a higher rate compared to the smallest size particle. While the magnitude of increase in performance decreases as then number of plates increases, the calculations show there is still added value of including the 9 sets of plates used in the current ELF design.

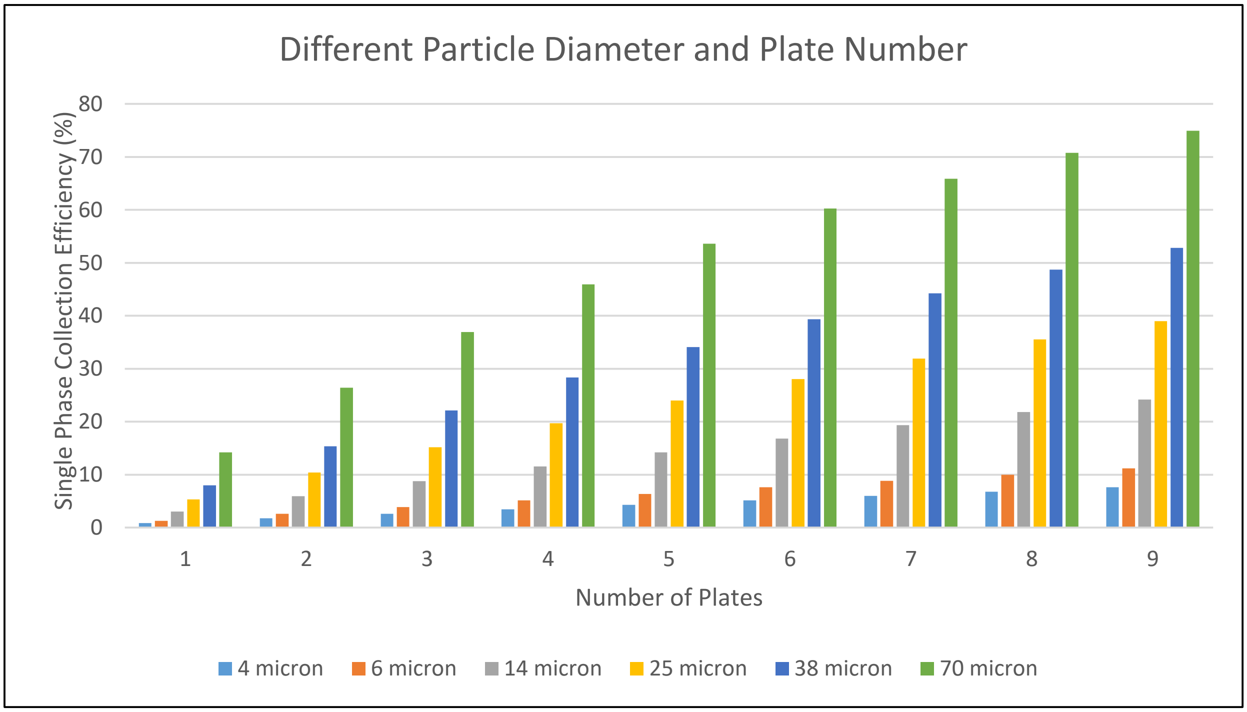

Figure 4: Single pass collection efficiency for different particle size and plate number

As stated previously, these calculations are based on a single-pass efficiency, where the fluid is treated and not recycled back into the system. In reality, the fluid is returned to the reservoir, mixed with the oil in the system, and continues to be re-filtered through the ELF filter. A simple way to represent this is to use the term "cycle" to represent the time when the entire volume of the reservoir is passed through the filter, assuming there is no mixing occurring in the reservoir. This provide a way to relate the reservoir volume to the filter rate in units of time (reservoir volume/circulation rate). For example, for a reservoir volume of 10,000 gallons and a circulation rate of 5 gpm (7200 gallons/day), one cycle would take 10,000 gallons divided by 7200 gallons/day or 1.39 days/cycle. If the system was operated for 30 days, the number of theoretical cycles would be 30 days divided by 1.39 days per cycle, or 21.5 cycles.

Figure 5 shows the overall collection efficiency as a function of cycle number, and as expected, shows that as the cycle number increases so does the overall collection efficiency. This means that high overall efficiencies can be achieved, even though the single pass efficiencies are not that high. This is an important consideration in the design philosophy of the ELF filter which allows for a compact design with relatively low electrical requirements being able to achieve optimal performance. This figure also shows the difference in collection efficiency afforded by particle size. Figure 3 shows us 3 different size (4, 6 and 14 micron chosen as they represent the three markers for the ISO testing) particle collection efficiency compare with the cycle numbers. From this figure we can see that the 14 micron particle took 17 cycles to reach 99% removal while the 6 and 4 micron took 39 and 59 cycles to achieve the same near pristine state. The time required to achieve these number of cycles is controlled by the variance of the reservoir size and filter circulation rate, and as will be seen from actual data collected in the field, can be accomplished in a reasonable amount of time.

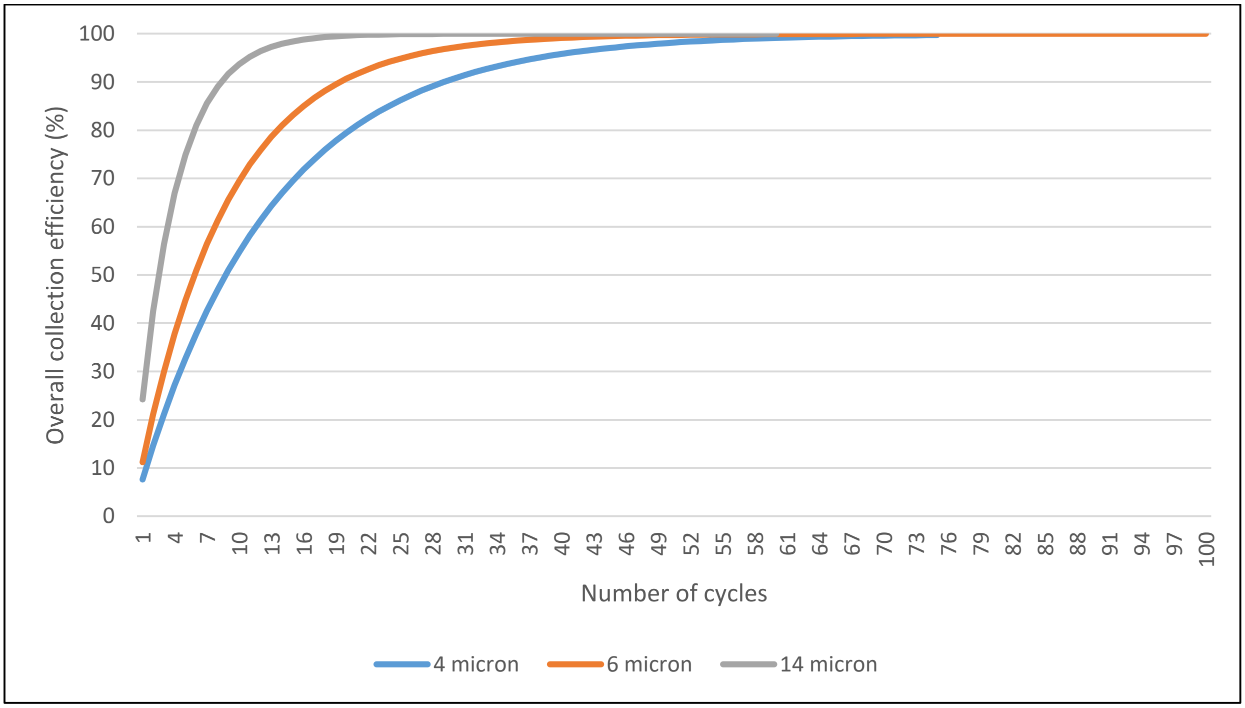

Figure 5: Overall collection efficiency relation with three different particle size and cycle number

The data in Figure 5 shows the case for three different mono-sized particle distributions. As we know, in reality the system will contain a distribution of many different sized particles. Therefore, the actual relationship between cycle number (time) and removal efficiency will vary depending upon that distribution. To illustrate, if we take an arbitrary size distribution of 50% - 4 micron particles; 20% - 6 micron; 5% - 14 micron; 5% - 25 micron; 10% - 38 micron particle 10%, 10% - 70 micron particles, the ELF system would take 51 cycles to reach 99% collection efficiency with 9 collection plates (Figure 6). This more closely represents how the system would behave in the real-world.

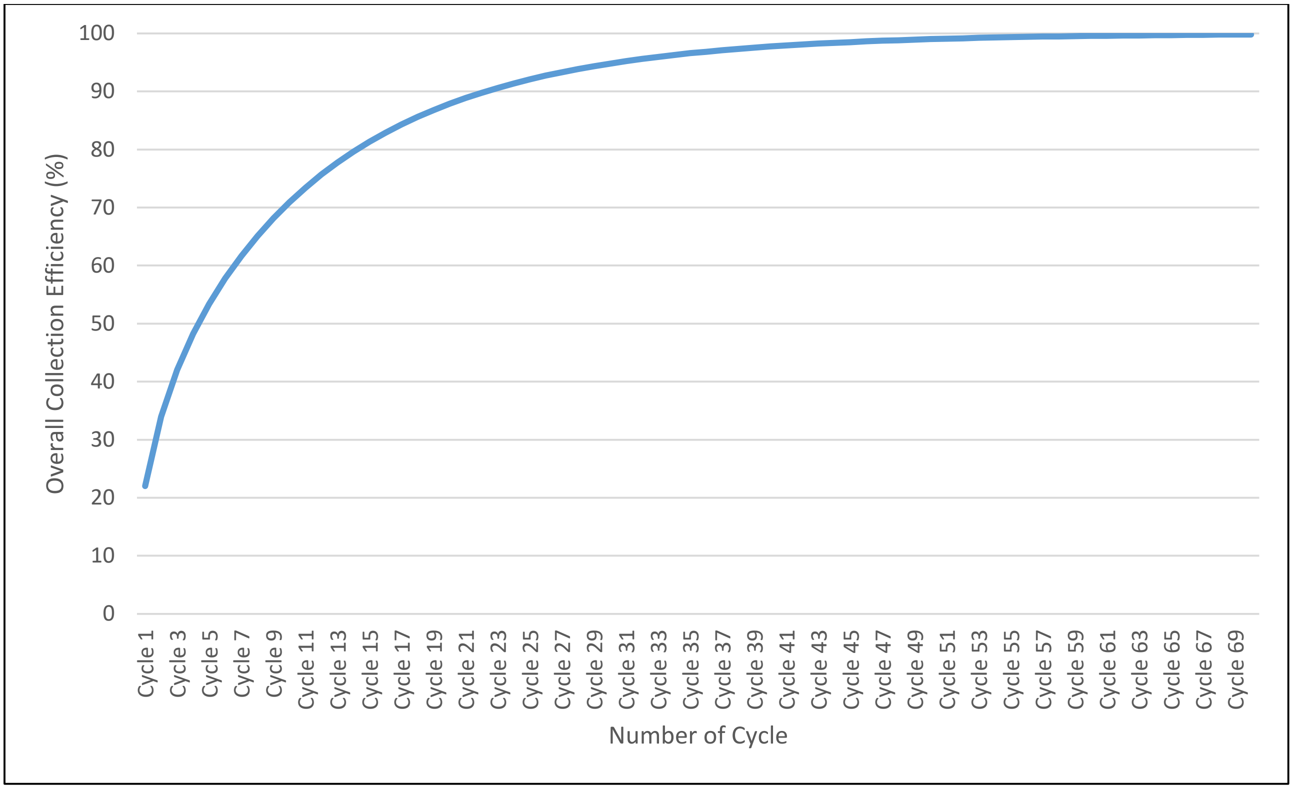

Figure 6: Overall collection efficiency relation with cycle number for combination of different particle size

Field Data

Modeling efforts are important in that can help drive design decisions and can demonstrate the potential for a device to accomplish the design objective. However, in order to have value the model must show similar trends as observed in the field. ELF Technologies recently completed two field tests with it's larger unit, one at the Leland Olds Station and one at the Coyote Station, both lignite-fired electrical generating plants located in North Dakota. The Leland Olds plant has reservoir size of 12,000 gallons and had starting particle counts of 9030, 2180, and 390 for the 4, 6, and 14 micron sizes, respectively. The Coyote plant, in contrast has a 4500 gallon reservoir and had starting particle counts of 1250, 520, and 80 for the 4, 6, and 14 micron sizes, respectively. Figures 7 and 8 show that in both cases, high removal efficiencies were obtained, showing the same trend versus time as predicted in the theory developed here. In both of these field tests, the circulated oil had particle counts had been reduced to levels equivalent to pristine oil by the end of the testing.

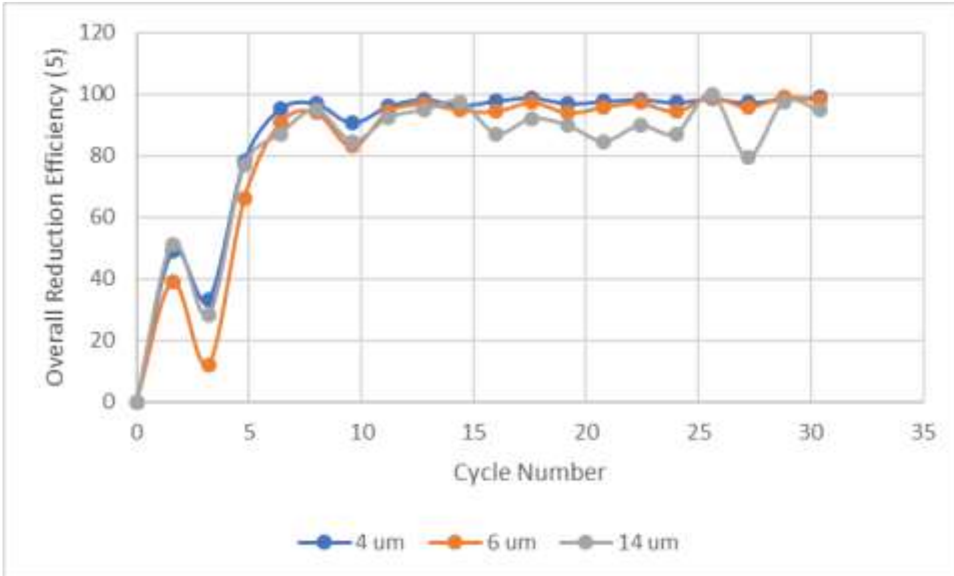

Figure 7. Reduction of particle counts for the field test at the Leland Olds Station

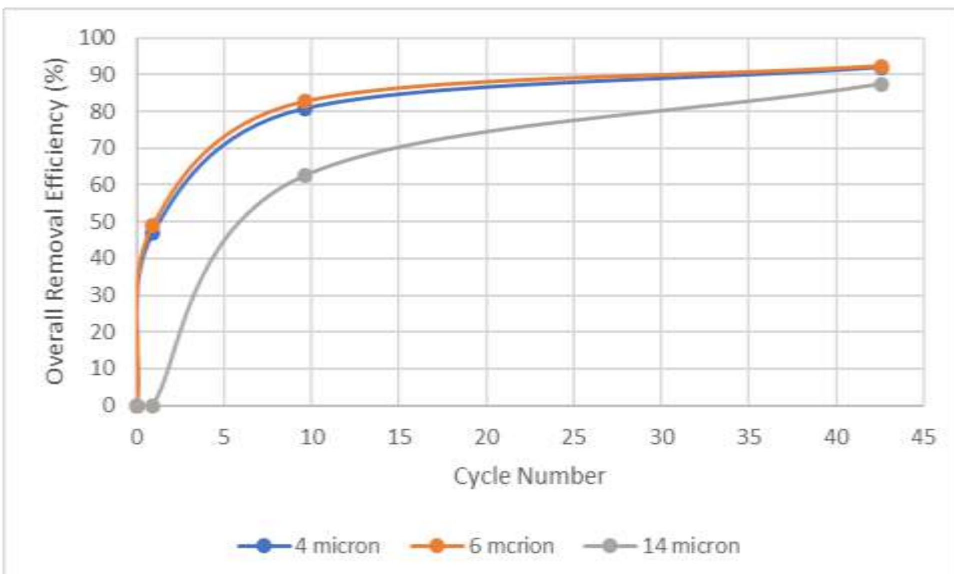

Figure 8. Reduction of particle counts for the field test at the Coyote Station

Conclusion

This is a novel technology with limited research and mathematical models available to reference. The idea of using ESP technology with a fully liquid media has not fully been explored. Many assumptions were required to be made relating to particle charges, corona onset voltage, and field strengths. The mathematical calculations demonstrate the potential of this approach to remove metal impurities from an oil. Results from theoretical calculations are reinforced with field testing which show trends that are in agreement with the calculations provided in this paper.

Recommendations/Future Work

For maximum filtration efficiency, the technology should be operated at the maximum voltage, with minimum electrode spacing, and substantial number of projection points. Experimental work at the University of North Dakota Institute for Energy Studies will look to close the gaps in knowledge and add to the database of information available in order to provide a more robust validation of the equations presented here. The assumptions and equations used herein will be refined where needed based upon additional information collected during field trials.

Prior experimental work completed at the Toyohashi University of Technology in Japan suggests that the optimal variable set points for peak filtration are as follows:

1. Density of Projections
2. Electrode Spacing
3. Applied Voltage
4. Oil Temperature

Our work would look to follow similar parameters and see the impact they have on the electrostatic lubrication filtration efficiency with the goal of continued refinement and miniaturization of the technology.

References

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15.2 Letters Of Support and Cost Share Contributions

ELF Technology, LLC.
4200 James Ray Dr.
Grand Forks, North Dakota 58202

Nicholas Dyrstad-Cincotta (M.Sc.)
Engineer, Institute, for Energy Studies
University of North Dakota
Collaborative Energy Center, Room 246
2844 Campus Road, Stop 8153
Grand Forks, North Dakota 58202-8153

Re: Lignite Energy Council

Dear Nic,

ELF hereby agrees to enter into and participate financially in The Lignite Energy Council's program to further develop the ELF technology for the lignite power generation community in North Dakota. ELF agrees to contribute $160,454 in kind and cash as elaborated in the schedule of contributions elaborated in the proposal.

Having obtained written commitments from both the Coyote and Leland Olds facilities, we are anxious to begin the next phase of development and to prove out the long term value proposition and how deployment of this technology can greatly reduce the operating budgets of the power generation facilities and provide real time data to enhance operational decision making.

Thank you for the opportunity to participate in the North Dakota lignite industry in partnership with the UND School of Engineering.

Most Sincerely

James K. Rickson
President & CEO
ELF Technology, LLC.

Coyote Station
6240 13th Street Southwest
PO Box 339
Beulah, North Dakota 58523-0339
701-873-2571
www.otpco.com

September 25, 2020

Mr. Nicholas Dyrstad-Cincotta
M.Sc., Mechanical Engineering
Engineer, Institute for Energy Studies
University of North Dakota
Collaborative Energy Center, Room 246
2844 Campus Road, Stop 8153
Grand Forks, ND 58202-8153

Re: Support Letter for the UND-led Proposal Entitled: "Electrostatic Filtration of Large Lubricant Reservoirs"

Dear Mr. Nicholas Dyrstad-Cincotta:

This letter expresses our support for your project titled "Electrostatic Filtration of Large Lubricant Reservoirs". This proposal is in direct alignment with our company's goals to extend operations between down-times and decrease overhead through adopting your novel oil filtration technology. In late 2019, we were pleased to host ELF at our Coyote Station power plant for preliminary trials. The ELF technology easily integrated and operated seamlessly with our process. The preliminary lab results are promising and have the potential to make a notable impact at our facility. We believe that the commercialization of this technology may have direct impacts to Coyote Station and the State of North Dakota.

We understand the technology is based upon extending the lifetime of turbine lubrication through electrostatic precipitation and is currently in the process of scale-up/commercialization. This effort is of interest to Coyote Station for reducing down-time of equipment. We agree to support the project with up to $20,000 of in-kind expenses, including: i) offering our facility to host a field demonstration, ii) Assistance with oil sampling and analysis, and iii) engineering support given through technology review in teleconference and in-person meetings. We also agree to send samples for analysis according the sampling protocol established by UND for the length of the field demonstration.

We look forward to working with the UND team on this exciting opportunity. If you have questions or require additional information, please do not hesitate to contact me at the letterhead address.

Sincerely,

September 30, 2020

Mr. Nicholas Dyrstad-Cincotta
M.Sc., Mechanical Engineering
Engineer, Institute for Energy Studies
University of North Dakota
Collaborative Energy Center, Room 246
2844 Campus Road, Stop 8153
Grand Forks, ND 58202-8153

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Dear Mr. Nicholas Dyrstad-Cincotta:

This letter expresses our support for your project titled "Electrostatic Filtration of Large Lubricant Reservoirs". This proposal is in direct alignment with our company's goals to extend operations between down-times and decrease overhead through adopting your novel oil filtration technology. In late 2019, we were pleased to host ELF at our Leland Olds Station power plant for preliminary trials. The ELF technology easily integrated and operated seamlessly with our process. The preliminary lab results are promising and have the potential to make a notable impact at our facility. We believe that the commercialization of this technology may have likely benefits to Basin Electric Power Cooperative as well as other large quantity lubricant users in the State of North Dakota.

We understand the technology is based upon extending the lifetime of turbine lubrication through electrostatic precipitation and is currently in the process of scale-up/commercialization. This effort is of interest to Basin Electric for reducing down-time of equipment. We agree to support the project with up to $20,000 of in-kind expenses, including: i) offering our facility to host a field demonstration, ii) Assistance with oil sampling and analysis, and iii) engineering support given through technology review in teleconference and in-person meetings. We also agree to send samples for analysis according the sampling protocol established by UND for the length of the field demonstration.

We look forward to working with the UND team on this exciting opportunity. If you have questions or require additional information, please do not hesitate to contact me.

Sincerely,

Russell Bosch
Maintenance Superintendent
Basin Electric Power Cooperative
Leland Olds Station
3901 Highway 200A | Stanton, ND 58571
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BASIN ELECTRIC POWER COOPERATIVE
A Touchstone Energy® Cooperative

15.3 Resumes Of Key Personnel

JUNIOR NASAH, M.S.

Major Projects Manager, Institute for Energy Studies

University of North Dakota

Education and Training

University of Buea, Cameroon	Chemistry	B.SC 2007
University of North Dakota	Chemical Engineering	M.S. 2012

Research and Professional Experience

2019-Present Major Projects Manager, UND Institute for Energy Studies.

2012-2018 Research Engineer, UND Institute for Energy Studies

2009-2012 Research Assistant, UND Department of Chemical Engineering

2009 Quality Assurance and Control Assistant, Fermentations Cameroon

Publications (Selected)

- Srinivasachar, S., **Nasah, J.**, Laudal, D. "Mitigation of Aerosol Emissions from Solvent-based Post-Combustion CO2 Capture Systems." US Department of Energy Agreement No. DE-SC0015737. April 2017.
- **Nasah, J.,** Jensen, B., Dyrstad-Cincotta, N., Gerber, J., Laudal, D., Mann, M., Srinivasachar, S. "Method for separation of coal conversion products from oxygen carriers." International Journal of Greenhouse Gas Control. Volume 88, July 2019, Pages 361-370.
- **Nasah, J.**, Srinivasachar, S., Laudal, D., Feilen, H. "Method for Separation of Coal Conversion Products from Sorbents/Oxygen Carriers." Proceedings, International Pittsburgh Coal Conference, 2017.
- Pei, P., **Nasah, J.**, Solc, J., Korom, S. Laudal, D., Barse, K. "Investigation of the feasibility of underground coal gasification in North Dakota, United States." Energy Conversion and Management. Volume 113, 1 April 2016, pages 95-103.

Synergistic Activities

Principal areas of expertise are advanced combustion systems, emissions control for advanced and traditional coal power generation. He has specific expertise on fluid-bed based technology development, leading the development effort for all fluidized bed systems of the CLC group. He has extensive experience in emissions monitoring at bench, pilot and field scale, and has performed multiple combustion-based testing for technology development or verification.

Other areas under which Mr. Nasah has been active include coal-based pollution measurement and control (sulfur oxides, aerosol formation and nitrogen oxides); underground coal gasification, coal beneficiation and natural gas processing. Mr. Nasah has over five years' experience in particulate sampling at coal-fired power plants as well as project planning, management, reporting, and day-to-day activities associated with bench-scale research programs.

ELECTROSTATIC FILTRATION OF LARGE LUBRICANT RESERVOIRS

Nicholas Dyrstad-Cincotta
Engineer
Institute for Energy Studies

2844 Campus Rd, Stop 8153
Grand Forks, ND 58202-8153

Education and Training

University of North Dakota	Mechanical Engineering	B.S. 2018
University of North Dakota	Mechanical Engineering	M.S. 2018

Research and Professional Experience

2018-Present Engineer, UND Institute for Energy Studies.

Currently, Mr. Dyrstad-Cincotta is the lead researcher and experimentalist at the Institute for Energy Studies for the development of a bench-scale Solar Desalination water treatment project called: Supercritical Water Extraction – Enhanced Targeted Recovery (SWEETR™). Additionally, he was the lead experimentalist of the previous lab-scale Phase I Supercritical Treatment Technology for Water Purification project at UND. Mr. Dyrstad-Cincotta had a major role in designing, fabrication, operation, programming, and reporting for both of these supercritical water projects. Development was based on experienced gained over several years of working on high temperature and pressurized systems with mentoring from experts in developing advanced energy systems. Mr. Dyrstad-Cincotta also served as the technical lead on the North Dakota Department of Commerce funded project: Electrostatic Lubrication Filtration (ELF).

Mr. Dyrstad-Cincotta's other responsibilities include identifying, developing and executing research projects specifically in water treatment, carbon capture, and air pollution control from energy-based sectors. Mr. Dyrstad-Cincotta was one of the lead technology developers in the Institute for Energy Studies Chemical Looping and Combustion (CLC) group. Key developer of a char separation technology to segregate fuel combustion products (char and ash) from oxygen carriers. Key researcher in development and testing of newly awarded Spout-Fluid Bed – based CLC technology. Development includes integration of the char separation technology and the novel spout fluidized bed system for CLC. Assists in the development of new oxygen carriers, reactor vessels and non-mechanical flow control valves for the new CLC system.

2016-2018 Junior Engineer, UND Institute for Energy Studies.

Key developer and a lead experimentalist for the Phase II continuation of the High Capacity Sorbent and Process for CO_2 project - Enhanced Capture of CO2 with Hybrid Sorption: E-CACHYS^{TM} bench scale project. Additional responsibilities include process and mechanical design, fabrication, programming, and operation of the several research projects awarded to the University of North Dakota – Institute for Energy Studies.

2015 Quality Engineering Co-op, United Technology Corporations Aerospace Systems.

Gained extensive knowledge in quality engineering, lean manufacturing, and product/process design. In this role, I delivered quality controls and enhancements to proactively address problems and improve product quality, manufacturing flow, customer satisfaction and bottom-line results. My responsibilities included verifying the quality and performance of the products in addition to troubleshooting the rectification of any existing errors or defects through product failure mode effects analysis (PFMEA).

Additionally, I worked to improve the efficiency of production operations, prepare engineering drawings in AutoCAD, ensure ISO compliance, and managed the engineering change process.

2013-2016 Research Assistant, UND Institute for Energy Studies.

Researched and developed several sorbent-type technologies. Sorbents for the capture of post-combustion CO_2 from coal-fired power plants. Key personnel for implementing Capture from Existing Coal-Fired Plants by Hybrid Sorption Using Solid Sorbents Capture CACHYS^{TM} technology - a High Capacity Sorbent and Process for CO_2 Capture lab-scale project awarded in 2013.

Selected Publications/Presentations

Tomomewo, O. S., **Dyrstad-Cincotta, N**., Mann, D., Ellafi, A., Alamooti, M., Srinivasachar, S., & Nelson, T. (2020, September 18). Proposed Potential Mitigation of Wastewater Disposal Through Treated Produced Water in Bakken Formation. American Rock Mechanics Association.

Dyrstad-Cincotta, N. "Supercritical Treatment Technology for Water Purification." North Dakota Energy Conference & Expo (NDECE), Grand Forks, ND. November 2019.

D., Mann, M., Srinivasachar, S., **Dyrstad-Cincotta, N.** "Supercritical Treatment Technology for Water Purification." U.S. Department of Energy (DOE) Solar Energy Technologies Office (SETO) Concentrating Solar-Thermal Power (CSP) Program Summit 2019, Oakland, CA. March 2019.

Nasah, J., Jensen, B., **Dyrstad-Cincotta, N.**, Gerber, J., Laudal, D., Mann, M., Srinivasachar, S. "Segregation of Unreacted Char from Oxygen Carriers During Chemical Looping Combustion." 5th International Conference on Chemical Looping, 24-27 September 2018, Park City, Utah, USA.

Nasah, J., Gerber, J., Laudal, D., Mann, M., Srinivasachar, S., **Dyrstad-Cincotta, N.**, Jensen, B. "Method for Separation of Coal Conversion Products from Oxygen Carriers." Journal, International Journal of Greenhouse Gas Control. 2019.

Synergistic Activities

Mr. Dyrstad-Cincotta principal areas of expertise are emissions control for advanced and traditional coal power generation and supercritical water treatment systems. He has specific expertise on fluid-bed based technology development, aiding in the development effort for all fluidized bed systems of the CLC group. Other areas under which Mr. Dyrstad-Cincotta has been active include coal-based pollution measurement and control (sulfur oxides, aerosol formation and nitrogen oxides), underground coal gasification, coal beneficiation and natural gas processing. Mr. Dyrstad-Cincotta has several years' experience in planning, executing and reporting of activities associated with lab and bench-scale research programs. He is also currently the lead programmer for process control systems (PCS) at the Institute for Energy Studies and has taken on the role of aiding the rest of the UND College of Engineering & Mines in their PCS design and programming efforts.

JAMES KEVIN RICKSON CV

From 2015 through the present, Mr. Rickson has been solely focused on developing and bringing the Electrostatic Lubricant Filtration (ELF) technology to market. In 2018, ELF Technology, LLC was formed, and entered into a partnering agreement with the University of North Dakota, Grand Forks (UND), Center for Innovation in 2019. This partnership was formed to modify and perfect the ELF technology for wind turbine applications, as well as others. Demonstrations and verification deployments have been run at the Otter Tail, Coyote Power Generation plant in Beulah, ND, and a white paper was produced under the auspices and oversight of the UND School of Engineering to document the veracity of the technology. At this time, ELF continues to work with UND School of Engineering to refine and implement a particle sensing technology to augment the efficiencies of the machines.

From 2010 through 2015, Mr. Rickson was a principal in The One Tree Group, LLC. (OTFG). OTFG worked to connect institutional investors to projects looking for long term funding. The client and investor base was international in scope, and OTFG concentrated on projects from $50 million to over $1 billion. It was during this timeframe that Mr. Rickson became acquainted with the Electrostatic Lubricant Filtration technology. The technology was so disruptive that Rickson formed a new company and, over time, concentrated his focus and efforts to bringing this filtering solution to market.

Previous life experiences and work credentials:

As Executive Vice President of International Development for Al Ahli Group, Dubai, Rickson was the point person for the development of the 1.3 million sq. ft. Dubai Outlet Mall. Rickson oversaw the design, construction, and eventual opening at a 95% leased facility, handling all marketing and leasing decisions. James was instrumental and the first international executive to acquire a multi-country entertainment licensing deal for one of the most coveted entertainment brands outside of North America. Jim was the lead negotiator as it related to the acquisition of the Nickelodeon brand for theme park rights through the parent company of Viacom and MTVN. Jim helped lead the detailed creative process for the Marvel Studio Park in Dubai and other major attractions and retail venues with Dubai's most prestigious developer, Nakheel, the developer of the Palm Islands. Projects under this development agenda were valued in excess of $2 billion USD.

In addition, Rickson spent 3+ years working closely with government, NGOs and private developers throughout the peninsular of South Korea. Beginning with the $1.4 Billion USD Marvel Studios Theme Park in Busan, Korea, and subsequently working with Gale International in Incheon, Korea, Dreamwood, Hallyuwood, Robotland, Lippo Group, and a host of other entities on their IP themed entertainment venues throughout the peninsula. Each of these developments incorporated a Hollywood themed entertainment venue within a more significant premium Outlet mall development. Developed and maintains an extensive gaming network, local IP holders, legal, PR, Banking, Interpreter, competitive retail environments, and potential staff to draw from. Rickson has accumulated a wealth of knowledge about the culture, business environment, financial system, and Chinese and Korean mindset towards foreign involvement and Foreign Direct Investment in the Middle and The Hermit Kingdoms.

As Managing Director of S&B International, based in Dubai, United Arab Emirates, James's background was further cultured in international alliances that spanned from Eastern Europe to the rim of Asia Pacific Region. James opened international distribution and branding offices for S&B International in 17 foreign countries throughout this region, negotiating licensing agreements with foreign multi-national companies to represent the American Fortune 1000 corporations under master licensing agreement such as Anheuser Busch, Hershey's Chocolate, Estee Lauder General Foods, General Mills, Martin Emprex, Dunn Stores (Ireland), Marks & Spencer (UK), Jovan Fragrances, Clinique, and many more. James went on to assign his teams in the creation of all globally compliant marketing plans, sales forecasts, opening orders, and inventory tracking systems for these new agents. Negotiated vendor agreements both nationally and internationally.

Formed Middle East Oil Recovery Services, LLC. in Bahrain and worked extensively through Kuwait and the greater Middle East and North Africa (MENA) after the conclusion of the 1st Gulf War.

Formed a joint venture (Institutional Assets, Ltd.) with the Mutual Life Insurance Company of NY (MONY), owned 24.5%, and managed 1 million sq. ft. development in Kansas City, Mo. In addition, the JV established relationships with local developers and participated in extensive retail projects throughout the metropolitan area.

As Vice president of Corporate Affairs for Executive Hills, Inc. Rickson acquired an extensive negotiation background and experience with zoning applications, staff reviews, environmental overview, and council approval. Project management over design development of $300 Million, 1 million sq. ft Kansas City Place office tower and 600,000 Kansas City Merchandise MART projects with PBNA Architects and HNTB Architects. Worked with REITs and Insurance companies on construction and end loans and handled purchases and sales from and to institutional investors.

Handled all lease negotiations for 5 million sq. ft. of office and retail space combined with extensive warehouse development. Clients included Apple Computer, Black & Veatch Engineers, Federal Express, and Sprint et al.

Negotiated construction and end loans with Institutional investors such as Mutual of N.Y. (MONY), Travelers, Teachers' Pension Fund, Aetna, Equitable, and The Morgan Banking Consortium. Also drafted sales and loan agreements with Shook-Hardy- Bacon, and Schuggart-Thompson law firms and designed and initiated global leasing structures for these projects.

Joined Gulf Oil, Corp. as a land agent and negotiated mineral interest rights for Gulf Mineral Resources, Inc. throughout the oil & gas fields and coal substrata across the United States.

EDUCATION:

Bachelor of Science, Management and Finance University of Missouri, Kansas City

30 hours of MBA work, Strategic Planning at University of Missouri, Kansas City

Petroleum Institute of America, Landman's certification in negotiation strategies

Petroleum Institute of America, Title abstracting certification

Real Estate Broker's or Agent's license in Minnesota, Kansas, and Missouri

Member National Association of Real Estate Investment Trusts (NAREIT)